Stream Health Assessment for City of Bothell Streams: 2010-2016

Version 2016-01

January 2017

Andy Loch – City of Bothell

City of Bothell™

This page intentionally left blank.

Table of Contents

Figures

Tables

Executive Summary

The City conducted surface water quality monitoring to determine the effectiveness of City programs to protect, preserve and enhance surface waters. The health of surface waters was measured using the local stream's chemical, physical and biological conditions. The City has adopted programs and rules to protect and improve the health of streams, wetlands, and rivers, collectively referred to as critical areas.

The monitoring was designed to answer the question "Is what we are doing making a difference to the streams?" The monitoring used a broad set of measures to provide signals along the continuum of stream health. Several lines of evidence were used to obtain status and trends. They included: chemical (dissolved oxygen, pH, and conductivity), physical (temperature, habitat, sediment, and large wood), and biological (stream insects, and fish populations).

The overall trend from 2010 to 2016 among all streams has been one of decline in stream health. Some metrics remained nearly unchanged through the study period and include; channel substrate, aquatic habitat, fish diversity, and large instream wood. Metrics that declined include: macroinvertebrates, stream temperature, dissolved oxygen, and pH. No metric trend showed consistent improvement over the study period.

The simple answer to the study's question, "Are things improving in our streams?" is "No." While some measures improved between 2010 and 2013, by 2016 they were again in decline.

There remain concerns that if current trends continue, by the next bioassessment in 2019, conditions will have degraded further. The results indicate a need to re-consider current management strategies. The recommendation is to evaluate the current management approach in light of the City's goal to protect and restore the health of city streams. The evaluation should investigate individual program actions to determine those that produce improvement from those that either insignificantly do or do not produce improvements.

Introduction

The City of Bothell's Comprehensive Plan, *Imagine Bothell…*, calls for actions to "protect, preserve, and enhance those features of the natural environment which are most sensitive to human activities." Collection of data and observations (i.e., monitoring) is one means to determine attainment of that goal.

The City of Bothell has adopted ordinances and department goals to protect, maintain, and restore its waters through knowledge of past, current, and future trends and conditions. The City of Bothell's Municipal Code 18.01.010 (27) defines Storm and Surface Water Management Services in part as "…water quality and environmental monitoring…." Ordinance 1968 (2006) effective in 2007 stipulates that expenditure of Surface Water Management fees be used to conduct Storm and Surface Water Management Services.

The monitoring effort will facilitate the City's commitment to wise management of land and water for the benefit of current and future generations. A primary measure of success will be attainment of beneficial uses as designated by city, state, and federal water quality standards.

Goal

A means by which the City of Bothell can measure and describe in a quantitative and qualitative manner our progress made to protect and restore the chemical, physical, and biological integrity of the City's surface waters.

Objectives

To monthly monitor surface water quality and every three years document stream channel conditions, habitat, macroinvertebrates, and fish populations to develop baseline data to identify trends. Results are to be used to inform and facilitate City policy and land use rules, to prioritize restorative actions, and to direct future program monitoring efforts. To the assessment to measure compliance with the Federal National Pollutant Discharge Elimination System (NPDES) Phase II permit, Endangered Species Act, and Clean Water Act.

Methods

Sample Station Selection

Selection of sites was determined through in-office review of maps and follow-up field surveys. Sites were selected based on their representativeness of the stream and upstream land use patterns. Sites were located as far downstream as was practical.

Chemical

At each site, monthly water quality measures were taken of dissolved oxygen, temperature, turbidity, conductivity, specific conductivity, and salinity. The samples were collected in the field using portable handheld meters.

Temperature

Stream temperatures were taken using two methods. One method required an instantaneous measure collected at the time of general water quality sample with YSI 85 meter. The second method involved use of a continuous instream temperature data logger. The data loggers were installed in streams at or near ambient monitoring stations of a subset of selected long-term monitoring and set to record continuous temperature every 15 minutes.

Physical

Hydrology Flows

Visual estimates of flow were made during monthly water quality sampling events. Flows were estimated and recorded in cubic feet per second (cfs) or, if flows were slight, estimates were made in gallons per minute (gpm) and then converted to cfs.

Pebble Counts

A Wolman pebble count was conducted at each stream reach sampled for macroinvertebrates. At each riffle sampled for stream insects, a measuring tape was placed perpendicular to stream flow across the selected riffle. A minimum count and measure of 50 pebbles were collected at each riffle within the ordinary high water mark. The four riffles sampled were cumulatively summed for each reach for a composite of one 200-pebble count. Analysis of data used transformation of the pebble counts to phi values. The phi values are then converted to D_{50} and D_{84} values and expressed as percent cumulative frequency. A D_{50} value of 5 can be interpreted as 50% of the substrate being 5mm or smaller, whereas a D_{84} value of 5 can be read as 84% of the substrate being 5mm or smaller.

Channel Morphology

At each of the four riffles sampled for macroinvertebrates, a cross section was taken of bankfull depth and width. A laser level was placed on top of the bankfull, leveled, and aimed perpendicular to the channel. Depth measures were read off of stadia rod at evenly-spaced intervals to obtain channel profile. Two ratios, bankfull width (BFW) to depth (D) and a wetted width (WW) to BFW, were calculated to assess channel characteristics.

Canopy

Canopy density is a measure of one's view to the sky while standing in the middle of the stream channel. A densitometer was used with the view taken from four orientations, then summed and averaged for a percent closure. It is a measure of how much sky is obstructed by the surrounding canopy. The measures were taken at each riffle sampled

for macroinvertebrates and then averaged for a single measure for the sampled stream reach.

Instream Habitat

A simple instream habitat assessment was conducted as recommended by Scholz and Booth, 1999. Only pools meeting TFW 1993 manual for minimum size and depth criteria were included in this report. Pool measures collected include pool residual width and depth. All other stream habitat (i.e. riffles and glides) were not collected in the surveys.

Large Wood

Large wood surveys stratified the count of pieces into four categories: Whether the wood was primarily a root wad or log and whether the wood was located in primarily wetted channel or within the bankfull width. To be counted, the wood needed to be a minimum of 1 meter (~3 feet) in length and greater than 25 cm (10 inches) in diameter.

Watershed Condition

Lengths of roads per square mile or road density were calculated. Total impervious surface was determined for each watershed and expressed as a percentage of area (Loch 2014). The number of acres of lakes and ponds and the percentage of wetlands were determined for each watershed basin. Streams were defined as piped or natural channel. For each watershed land use zones were identified and storm water systems, i.e. number of catch basins were inventoried. The watershed conditions were not updated for this report and represent conditions as of 2012.

Biological

Macroinvertebrate

Streams selected for bioassessments had a reach delineated that ranged from shortest of 27 wetted channel widths to 40 wetted channel widths in length. Standard methodology for reach is 40 wetted channel lengths. Urban streams often lack a clear uninterrupted reach of 40 wetted channel lengths. In cases of obstructed continuous stream channels, a shorter reach was sampled and noted.

Within the reach, four riffles were selected that were representative of the reach. Each riffle was sampled using a Surber Sampler and all four riffles were composited into one sample for lab assessment. The samples were shipped to a lab to perform a sort and 500-count of macroinvertebrates. Macroinvertebrates were identified to species and genus when possible. The results were scored using Fore 1999 Biotic Index of Biological Integrity (B-IBI) metrics.

Fish

Fish were captured using an electro-fisher gear. A onetime pass-through was conducted within the stream reach. Block nets were installed at the down and upstream ends of the sampled reach. All fish captured were identified to species, counted, and measured for fork length. Fish were returned to as near as possible to their point of capture.

QA/QC

To ensure accurate and precise data, all meters are calibrated at a minimum of once per month or per manufacturer's recommendations. Calibration records were kept of water quality meters. Meters were checked for accuracy prior to each monthly sampling event and calibrated according to manufacturer's recommendations.

Field data collection was supervised by a professional aquatic ecologist. A 10 percent replicate sample was collected for macroinvertebrate surveys. Macroinvertebrate samples were sent to an outside laboratory and subjected to the laboratory's QA/QC methods.

Data Analysis

Streams were assessed and described noting how and where impaired conditions occur. This report will summarize data from 2010 through 2016. Since monitoring began in 2010, sites have been added and dropped from the monitoring program. On average, 17 sites have been monitored each year through 2013. In 2013 several sites were discontinued and several new ones added. If analysis of a particular site found that there was little to no significant added value or uniqueness, the site was dropped and a new one added to take its place. In 2016, twelve sites were sampled monthly and seven sites received bioassessments.

The following measures were used to describe watershed and stream attributes for use in preparing a cumulative score. The score can be used to compare streams relative to other streams having received the same survey efforts. The attribute scoring was derived from study results of regional and local research, state water quality standards, and relative measures observed for streams in Bothell. The cumulative scores are solely for the use of comparing Bothell streams to each other and may have no broad regional use in other Puget Sound streams.

Attribute scoring for streams that received Bioassessments

1) ***Channel Substrate Conditions*** where % of fines < 2mm at > 15% of substrate (Scrivener and Browlee, 1989), score 1 if true; 2 if false.

2) ***Aquatic Habitat Diversity*** target condition ranking (May, 1996), score 5 if good; 3 if fair; 1 if poor.

3) ***Fish Diversity*** (relative measure based on City of Bothell stream survey results)
   - Score 5 = only native species with three or more species.
   - Score 4 = native and non-native species present and number of salmonid age classes is ≥3 and/or 2 or more salmonid species and other native non-salmonids have 2 or more age classes present.
   - Score 3 = native and non-native species present and number of salmonid age classes is ≥ 2.

- Score 2 = 1 or more non-native species are classified as Tolerant (Zaroban et al. 1999) and/or salmonids present with only one age class present.
- Score 1 = no fish present or only non-native species.

4) ***B-IBI, Biological Integrity of Macroinvertebrate Community***:
   - Score 5 = B-IBI value of ≥ 43 to ≤ 50, no impairment detected.
   - Score 4 = B-IBI value of ≥ 35 to ≤ 42, slight impairment.
   - Score 3 = B-IBI value of ≥ 28 to ≤ 34, moderate impairment.
   - Score 2 = B-IBI value of ≥ 20 to ≤ 27, severe impairment.
   - Score 1 = B-IBI value of ≥ 10 to ≤ 19, extreme impairment.

5) ***Large Organic Wood*** where large organic wood (LOD) frequency to BFW spacing target condition classified (May, 1996), score 5 if good; 3 if fair; 1 if poor.

6) ***Stream Temperature*** based on WDOE WQ standards:
   - Score 5 = no excursion of WDOE WQ standards.
   - Score 4 = excursion of WDOE WQ standards for 13 C 7DADMax from September 15 through May 15.
   - Score 3 = excursion of 16 C WDOE WQ standards.
   - Score 2 = excursions of 13 C and 16 C WDOE WQ standards.
   - Score 1 = any occurrence of lethal level temperatures to salmonids (> 23 C 1-day max or 7DADMax > 22 C), or between September 16 through June 14 1-day max > 17.5 C (lethal to developing fish embryos).

7) ***Dissolved Oxygen***, based on WDOE WQ standards and scientific literature concerning reduced growth and lethal levels to salmonids.
   - Score 5 = no measures below WDOE WQ standards.
   - Score 4 = minimum measure > 8.0 to < 9.5 mg/l.
   - Score 3 = minimum measure > 5.0 to < 8.0 mg/l.
   - Score 2 = minimum measure > 3.3 to < 5.0 mg/l or annual average below state standard of 9.5 mg/l.
   - Score 1 = minimum measure < 3.3 mg/l.

8) ***pH Levels***, if above or below WDOE WQ standards, score 1 if true; 2 if false.

The cumulative score was tabulated for each watershed that received a bioassessment. The results can be used to rank streams for future actions based on the individual impaired attributes and/or a water body's overall score. The lowest score possible is eight, 8; the highest score possible is thirty-four, 34.

Table 1. Cumulative Score and its stream health status indicator

Cumulative Score	Stream Health Condition
34 to 28	**Good:** no measurable signs of stress
27 to 21	**Moderate:** some signs of stress, some could be severe.
20 to 14	**Poor:** signs of moderate to severe stress across most measures.
≤ 13	**Severe:** typically all measures show high stress.

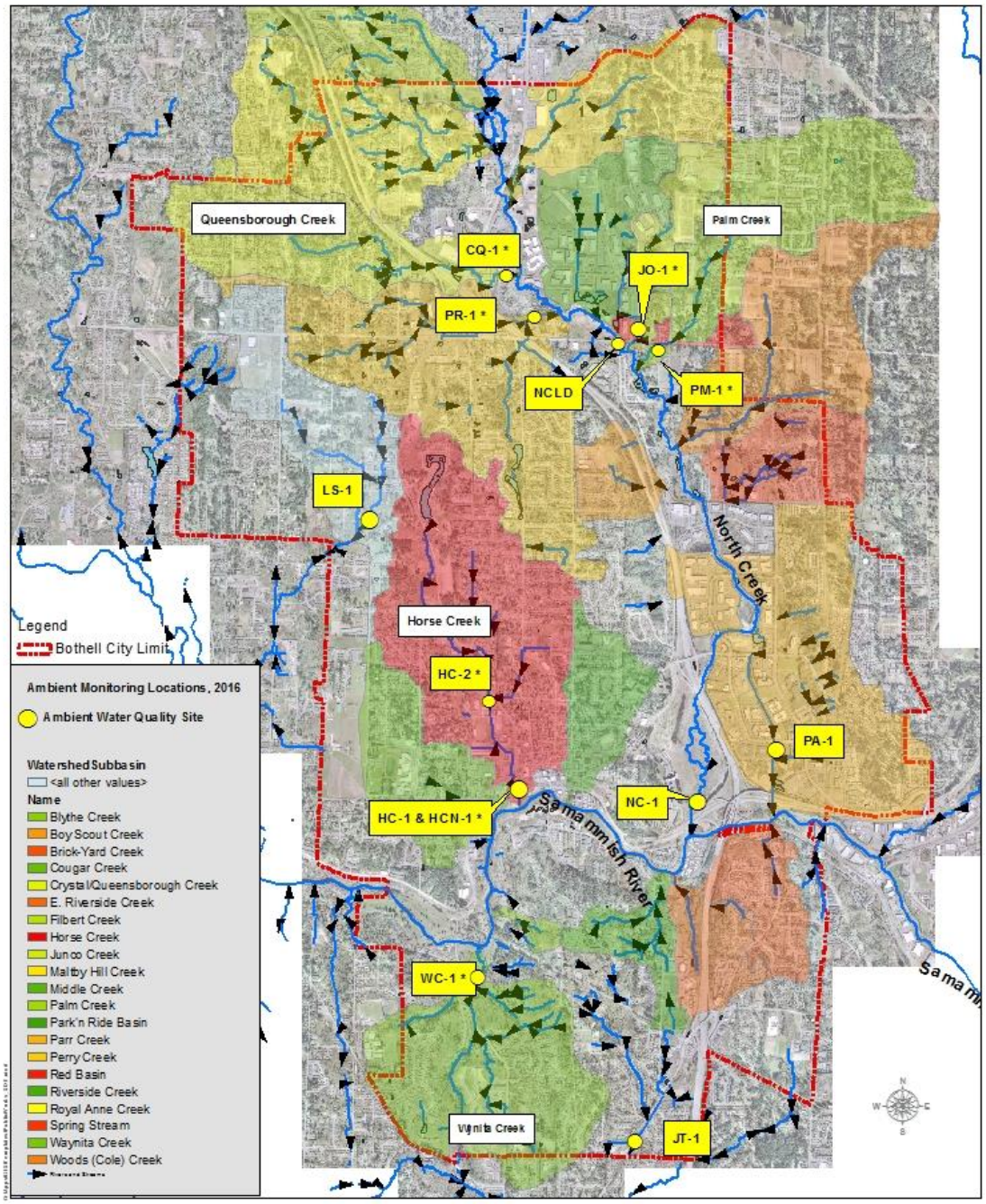

Figure 1. Water quality and bioassessment (*) sample locations for 2016.

Results

Sample Station Selection

A total of 12 sites (Figure 1) were monitored in 2016. Of those sites seven have been monitored since 2010. Since 2010 five new sites have been added and nine have been discontinued. Out of the 2016 sites the same six sites received bioassessments as in 2010 and in 2013. One new bioassessment site was added in 2016. The site is Horse Creek's new daylighted channel, HCN-1, near its confluence with the Sammamish River.

All sites were sampled once monthly for dissolved oxygen, conductivity, temperature, pH, salinity, turbidity (NTU), and visual flow estimates. Seven of the sites received a bioassessment in late summer of 2016. Data from year-round temperature loggers are available from six streams for 2015. Temperature logger data from 2016 is not available. Of the six sites with temperature loggers, three have nearly complete records since 2010 and the other three have nearly complete records since 2011.

Horse Creek basin had two sample stations, one near its confluence with the Sammamish River, the other north of NE 185th Street. In 2016 the downstream sample station was moved to the newly daylighted channel. North Creek has two sample stations, see Figure 1. All other basins had a single sample station.

Basin Descriptions:

Nine surface water management areas were sampled in 2016 (Figure 1). The City adopted the 2015 Storm and Surface Water Master Plan Update. The plan delineated eleven Surface Water Management Areas (SWMA), Figure 2, based on natural and built characteristics. The plan provides an overall description of land use, land cover, soil, wetlands, floodplain, surface waters, and storm infrastructure.

Watershed conditions were assessed using the City's geographic information system (GIS). Table 2 was based on conditions in 2012. It's summarized by individual basins: basin size, road density, total impervious surface, percentage of wetlands, level of imperviousness, and stream channel conditions (natural vs. piped).

Table 2. Summary of natural features by basin within Surface Water Management Areas (SWMA).

Stream	Total Basin Acres	In City Basin Acres	Natural Features[1] Lakes/Ponds Acres	% basin Wetlands	Stream miles within City Piped	Stream Natural Ch.	Road Length mi/sq. mi.	% Impervious
Parr Creek SWMA								
Parr Creek	749	719	2.37	4	0.22	2.27	13.1	42
Horse Creek SWMA								
Horse Creek	743	714	8.1	3	0.7	1.75	14.1	36
Little Swamp Creek SWMA								
Little Swamp Creek	368	353	0.84	5.7	0.12	1.62	11.4	27
Waynita SWMA								
Waynita Creek	563	425	1.16	2.7	0.3	4.09	10.7	23
Riverside SWMA								
Brick Yard Creek	160	155	0	0.8	0.15	0.26	21.9	41
Queensborough SWMA								
Perry Creek	702	702	6.89	8	0.37	3.69	17.6	37
Queensborough Crk	387	378	1.45	1.6	0.17	1.6	18.8	38
Canyon Park SWMA								
Middle Creek	268	268	2.99	6.5	0.06	1.25	8.8	48
Junco Creek	134	134	0.55	4.3	0.09	0.84	6.9	35
Maltby Hill Creek	321	304	2.14	13.7	0.05	1.89	11.3	27
Fitzgereald SWMA								
Palm Creek	436	103	0	3.9	0.11	0.74	14.9	28
Woods Creek	435	80	1.6	19	0.09	0.88	6.2	11
Juanita SWMA								
Juanita Creek	438	438		6		2.2		41

[1]Does not include measures for watershed parameters outside of city boundaries.

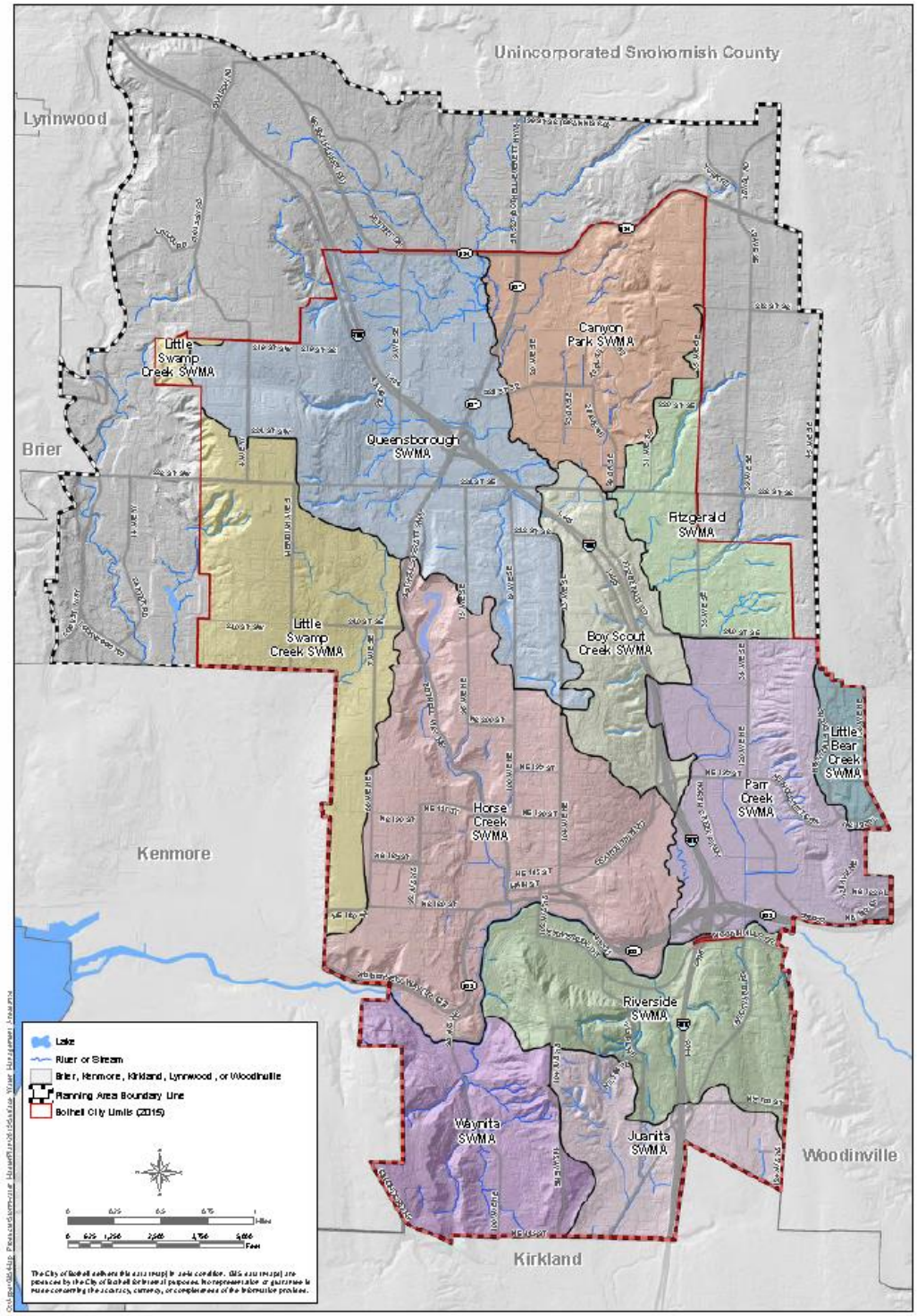

Figure 2. Surface water management areas.

Surface Water Management Areas

Parr Creek SWMA Results

Ambient Monitoring

The sample station is located just downstream of North Creek Business Park. When the business park was built in the 1980s the channel was dredged and modified into a trapezoidal shape. A temperature logger has been installed and maintained at this site since 2010 through 2016. This is the only sampled location for Parr Creek SWMA and has not received a bioassessment.

Dissolved oxygen (DO) is not supporting fish usage throughout most of the year. An annual average is below DO of 6 mg/L. Salmonids for core summer rearing require DO levels of 9.5 mg/L and above. During every year except 2016 for a period of up to six months the DO levels were below the lethal level to salmonids, <3.3mg/L. In 2016 the DO never reached lethal levels to salmonids.

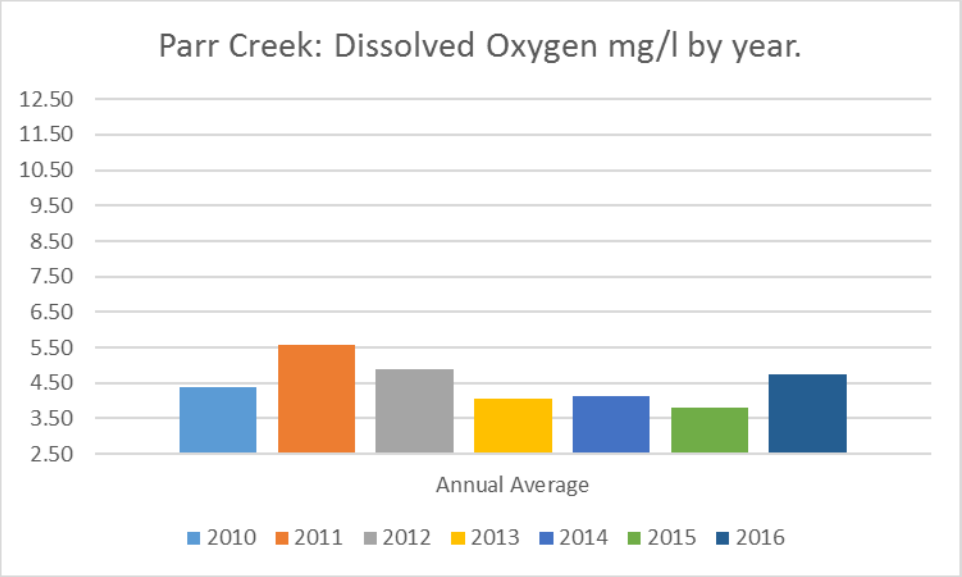

Figure 3. Parr Creek dissolved oxygen mg/l by year.

Temperature

Parr Creek has had one of the longest running temperature logger stations of all sites sampled. Figure 4 summarizes the data by annual percentage of days that exceeded state standards. The standard is a seven-day running average not to exceed 16 degrees Celsius.

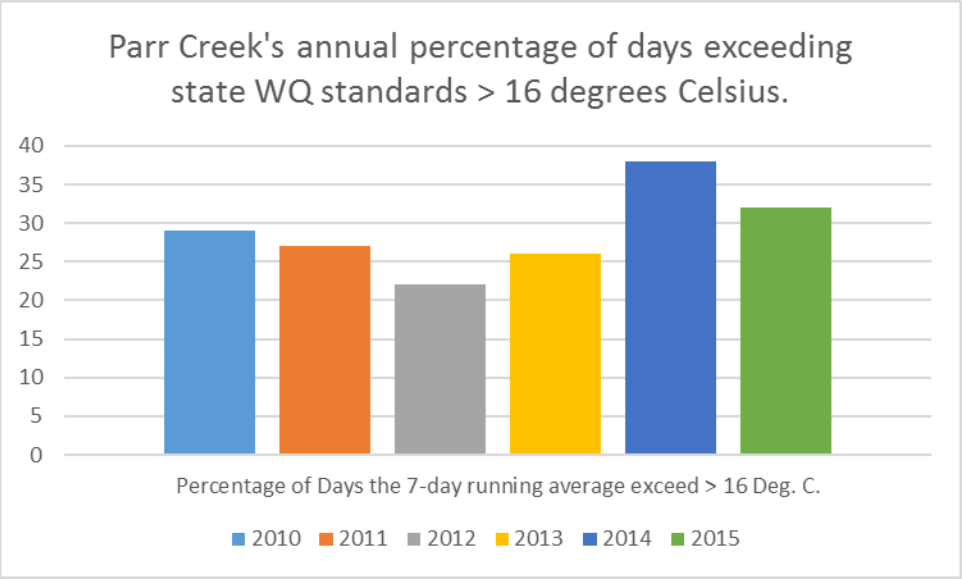

Figure 4. Parr Creek's percentage of days exceeding state WQ standards.

Conductivity in Parr Creek is at levels indicative of urbanized landscapes. These levels indicate higher than natural occurring levels of dissolved ions, metals, in the stream. Typically, forested watersheds have conductivity levels below 100 us/cm and lower. Conductivity levels were fairly consistent throughout the study period.

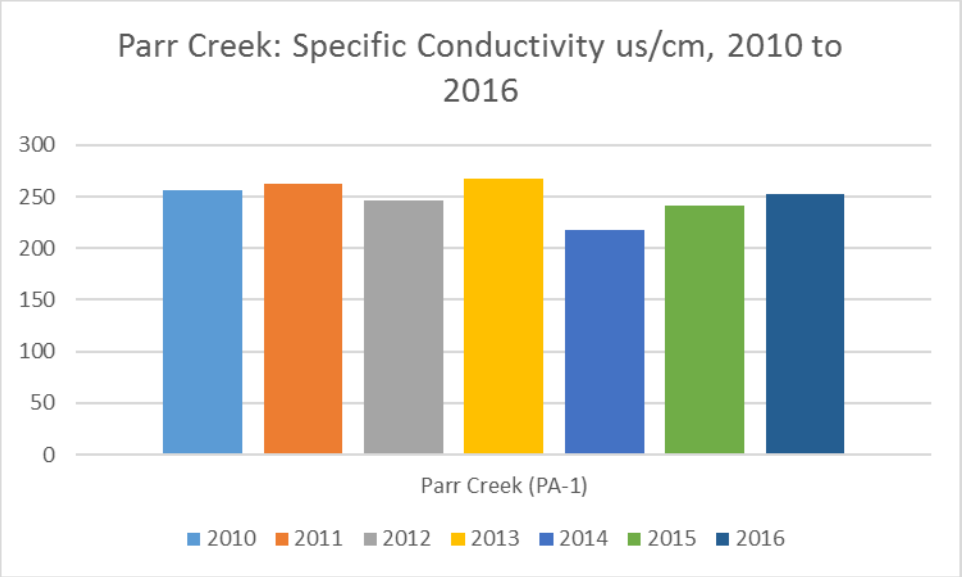

Figure 5. Parr Creek specific conductivity us/cm 2010 to 2016.

Parr Creek's annual pH has shown a decrease since 2010. During multiple years (2012, 2013, 2015 and 2016), monthly levels were below Ecology's standard of pH 6.5. The

lowest monthly pH value was a pH of 6.0 in February 2016.

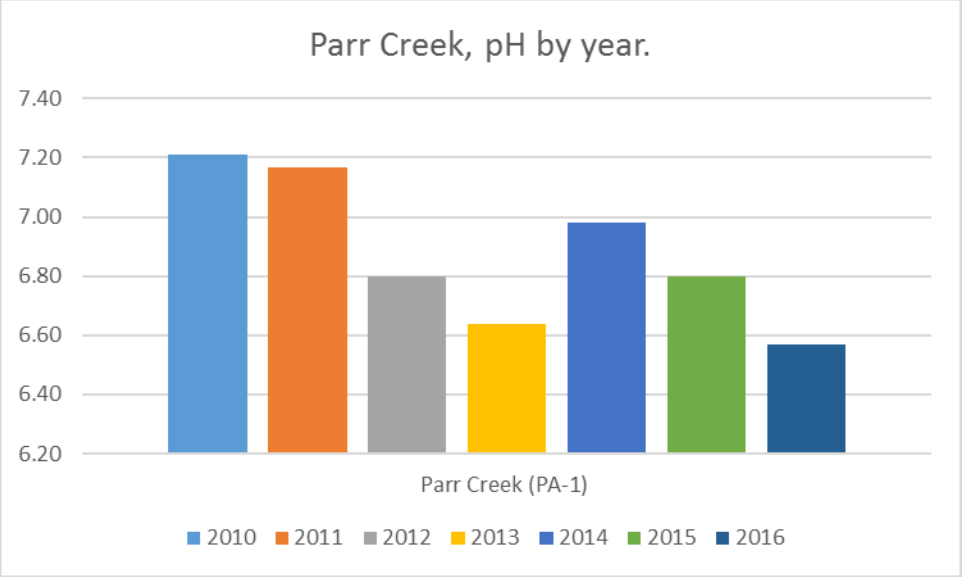

Figure 6. Parr Creek, annual average of pH by year.

Bioassessment

Bioassessments were not conducted on Parr Creek.

Discussion

Parr Creek has severe low dissolved oxygen and high summer temperatures. These two elements combine to make it nearly impossible for Parr Creek to support salmonids and most other native species through most of the year. Anecdotal observations have noted three spine stickle backs at times further downstream. Upstream of 120th Avenue SE stream conditions are considerably different. Previous monitoring found upstream temperature and dissolved oxygen to be of higher quality and able to support salmonids. In 2014 during an upstream fish removal effort, lamprey oomycetes were encountered. Previous upstream fish surveys, along 120th Avenue SE, by Washington Department of Fish and Wildlife, have documented cutthroat trout and three spine stickle backs.

The floodplain of North Creek, which Parr Creek flows through, has peat soils. The general nature of such soils is a high organic content that produces high biological oxygen demand on the water during decomposition. It is assumed that the decomposition of peat soils is the primarily responsible agent for the extreme low levels of oxygen.

The pH of peat soils also tends to be more acidic than non-peat soils. The decline of pH in Parr Creek could be due to the influence of the peat soils and not necessarily a change in storm runoff discharges to the stream. Imperviousness levels are the second highest of the studied streams, Table 2.

Horse Creek SWMA Results

Ambient Monitoring

Horse Creek had two sample stations established in 2010. One located in The Park at Bothell Landing, HC-1, near its confluence with the Sammamish River and an upstream station, HC-2, just upstream of 188th Street NE. In 2016 both stations were altered for the City's downtown revitalization channel daylighting project. A long-buried reach of Horse Creek within the downtown zone was relocated to the west of its historic location and daylighted. The confluence of Horse Creek in the Park at Bothell Landing was moved from east of the Lytle House to west of the children's playground. The new channel began receiving flow in late May 2016. Sampling at the new channel location, HCN-1, began in June of 2016. The upstream station, HC-2, received restoration in the form of placement of large wood, new stream channel substrate and setbacks of the riprap walls. The restoration at HC-2 affected about 40 feet of the channel immediately upstream of 188th Street NE. The new downstream station, HCN-1, is an entirely new channel.

Dissolved Oxygen

Dissolved oxygen for Horse Creek typically falls below state standards of 9.5 mg/ in the summer months, June through September. This has annually occurred since 2014. The lowest monthly DO readings at the downstream station, HC-1 was 7.70 mg/L in August 2012 and at HC -2 a 7.60 mg/L in August 2015. Annual average for 2014 through 2016 was at or slightly below state standards for both sites.

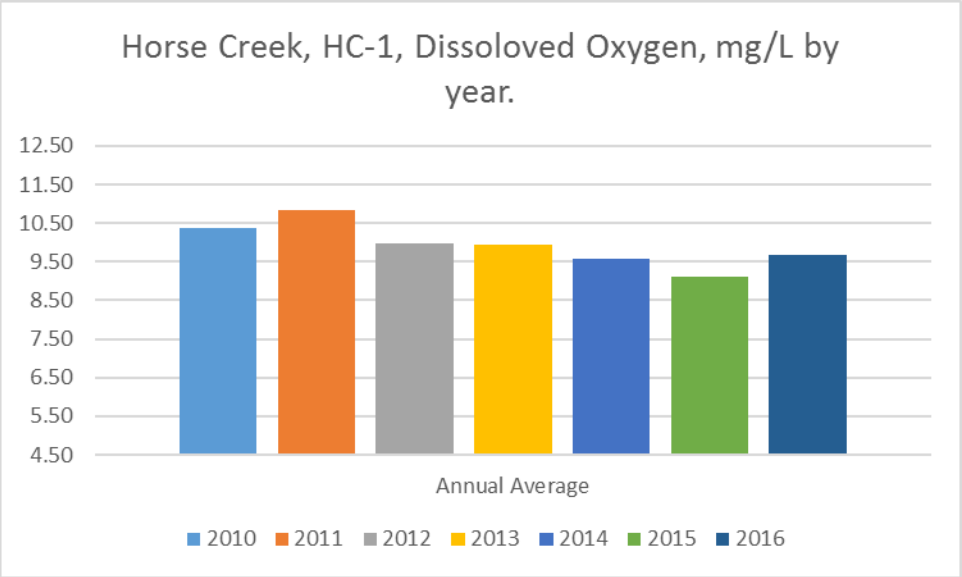

Figure 7. Horse Creek, HC-1 dissolved oxygen mg/l by year.

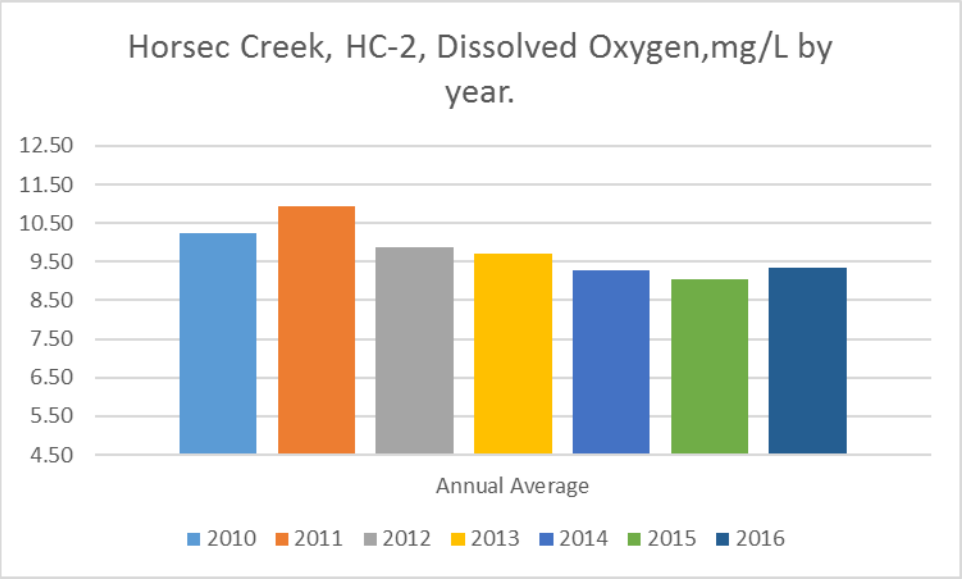

Figure 8. Horse Creek, HC-2, dissolved oxygen mg/l by year.

Temperature

Temperatures at the lower station exceed state temperature standards for various lengths each year. The 26 percent of days exceedance in 2015 occurred during of one of the warmest and driest periods ever recorded for the Puget Lowland region. Maximum temperature recorded at HC-1 was 21.5 C in August 2014 and at HC-2 a 21.4 c recorded in August 2013.

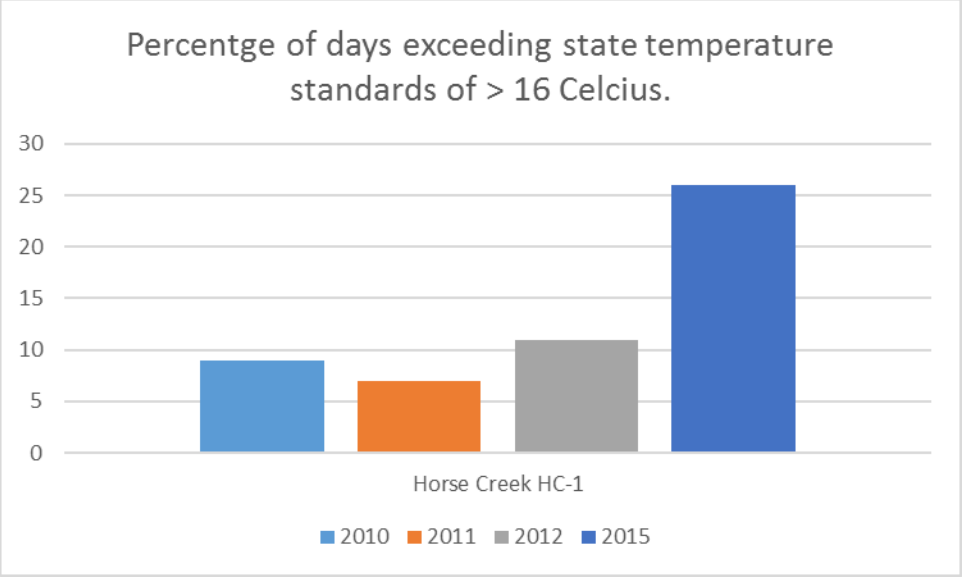

Figure 9. Horse Creek's percentage of days exceeding state temperature standards.

Conductivity

Lower Horse Creek tended to have higher levels of dissolved metal ions than upper Horse Creek. Both followed a similar trend between years. There was a notable decline in 2016 that was nearly at or below levels measured in 2012.

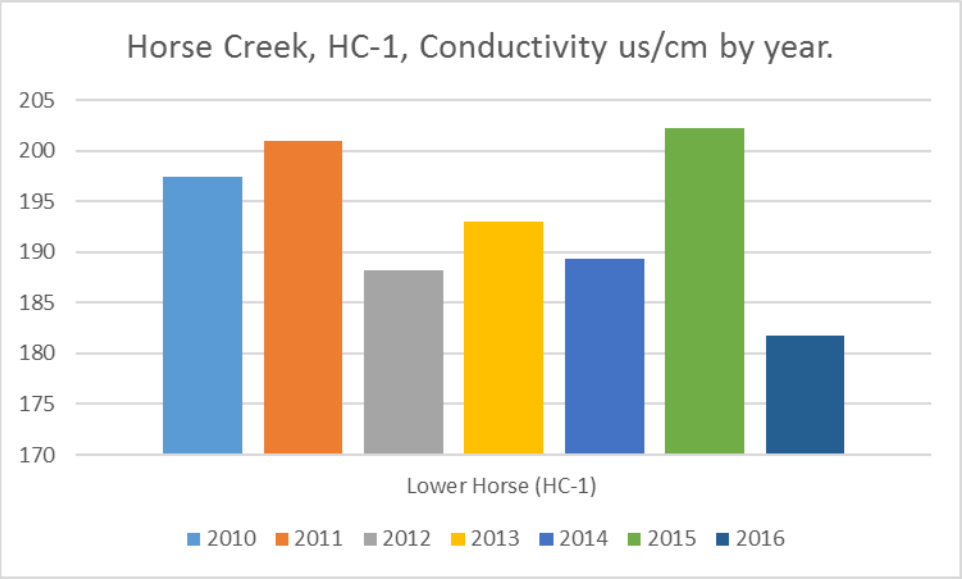

Figure 10. Horse Creek, HC_1, conductivity us/cm by year.

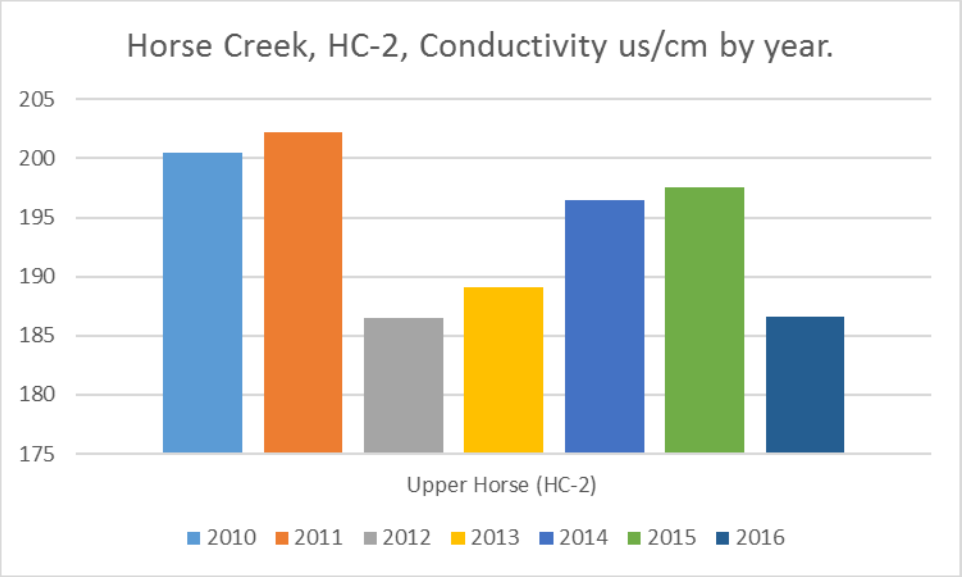

Figure 11. Horse Creek, HC-2, conductivity us/cm by year.

pH

The pH levels followed similar trends at both locations. During all monitoring periods neither site exceeded state water quality standards. Both sites are currently experiencing a decline, acidification, in pH since 2014.

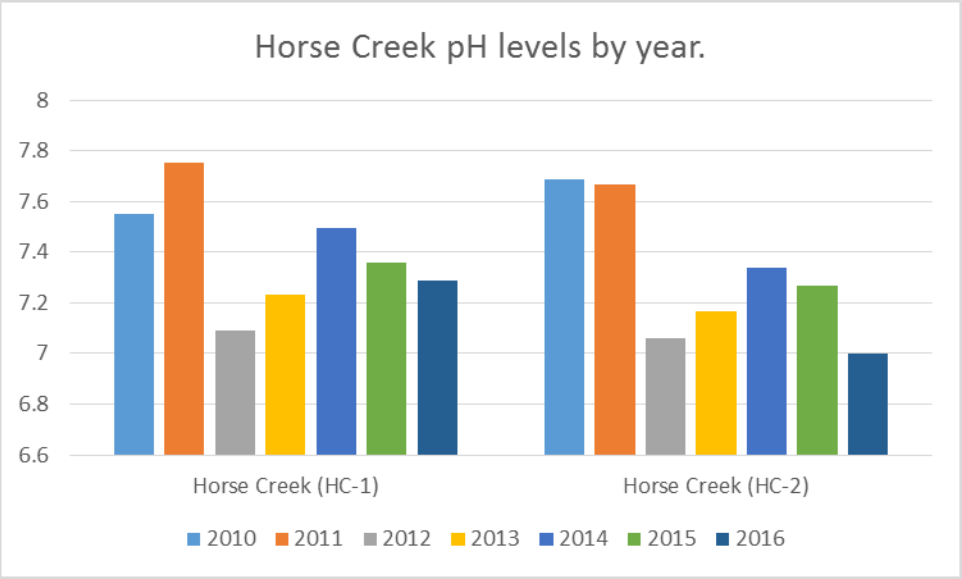

Figure 12. Horse Creek's pH levels by year.

Bioassessment

The upstream location, HC-2 received bioassessments in 2010, 2013, and 2016. The downstream location, HCN-1, was sampled only in 2016. The HCN-1 sample for biological surveys is of a brand new channel that was designed and constructed to improve stream health. The flow has only been occurring since May 2016.

Habitat - Wood

Surveys of the instream habitat measured quantity of pools, depth of pools, and pool surface area. Surveys found little change over the years at HC-2. The new channel had similar levels of habitat seen at HC-2. Pools are reflective of in-channel obstructions. Typically, in low gradient streams the presence of large wood is associated with increase in the quality of pool habitat.

Table 3: City of Bothell stream pool habitat surveys, HC-2 & HCN-1

HC-2 Year	# Pools	Residual Pool Depth	# Pools/ 100 M	Pools/ Bankfull Width	Pool Area Sq. M	% of Pool Area
2010	3	0.2	7.8	0.13	7.5	9.6
2013	3	0.36	4.3	0.2	20.9	38
2016	2	0.26	4	0.09	9.3	15
HCN-1						
2016	1	0.22	1	0.09	5.3	7

Large wood surveys at upper Horse Creek recorded no wood in 2010 and 2013. In 2016 the restoration of the lower portion of the channel had wood placed within the bankfull width. The wood was positioned outside the wetted channel and thus had not caused any pools to form. The downstream restored channel had high wood count within the bankfull channel but, like the upstream, all of the wood was outside of the active wetted

channel. The total number of wood pieces per bankfull width in HC-2 went from zero in 2010 and 2013 to three in 2016. In the new channel the number of pieces of wood within the surveyed reach was 34. They were all located outside of the wetted channel but within the bankfull channel. The wood interacts with the channel during high flow events.

Sediment

Stream substrate measures found relatively low fines in both reaches in 2016. The new channel's, HCN-1, substrate had 12 percent of fines. Fines are defined at being less than 2 mm. At HC-2 fines comprised 19 percent of the in channel substrate. At HC-2 in 2010 and 2013 had fines, < 2 mm, of 35 percent and 26 percent, respectively. The winnowing out of fines could indicate a change to upstream sediment sources. Fines at less than 15 percent indicate good conditions.

Fish

Surveys of fish in all three years 2010, 2013, and 2016, found no fish at the upper Horse Creek site. In the first year at lower Horse Creek's new channel, fish surveys found three reticulate sculpins and three non-native weather loaches. This is a positive signal that fish will utilize the new channel over time.

Stream Insects

There was little change throughout the study period at HC-2, Table 4. Its benthic index of biotic integrity (B-IBI) score remained at 16. Issues affecting the low score included a loss of mayflies, no caddisflies (Trichoptera), an increase of tolerant taxa to polluted waters, and lack of any intolerant taxa to polluted waters. It has good representation of long lived taxa and taxa richness. Stream insects at the new channel, HCN-1, were found to be similar to HC-2 with a slightly higher score of 20.

Table 4. Horse Creek's metrics and B-IBI scores.

	Horse Creek, HC-2			**HCN-1**
Year	**2010**	**2013**	**2016**	**2016**
METRIC VALUES				
Taxa richness	20	19	20	27
E richness	2	1	1	1
P richness	1	1	1	1
T richness	2	0	0	1
Intolerant taxa richness	0	0	0	0
Clinger richness	5	4	4	5
LL richness	1	3	2	0
% tolerant	1.05%	2.85%	4.76%	35.65%
% predator	2.46%	3.66%	4.76%	37.96%
% dominance (3)	89.28%	84.55%	75.71%	67.59%
B-IBI Score	**16**	**16**	**16**	20

Discussion

The dominant signals observed in the Horse Creek watershed are of overall severe aquatic health conditions. Causes include lack of diverse instream habitat, a poor streamside riparian zone, low dissolved oxygen, high stream temperatures, and high conductivity. This is expressed by an observed extreme level of impairment to the living biological instream community.

Little Swamp Creek SWMA Results

Ambient Monitoring

The sample station was located immediately downstream of 7th Avenue SE. This is the only sample location for Little Swamp Creek's SWMA and has not received bioassessments. The site has been sampled monthly since early 2010. It is also a long-term monthly sample site for fecal coliform bacteria.

Dissolved oxygen (DO) is not meeting state standards throughout most of the year. Minimum values of DO 5.12 mg/l were observed in July of 2016. The trend since 2013 is DO below state standards.

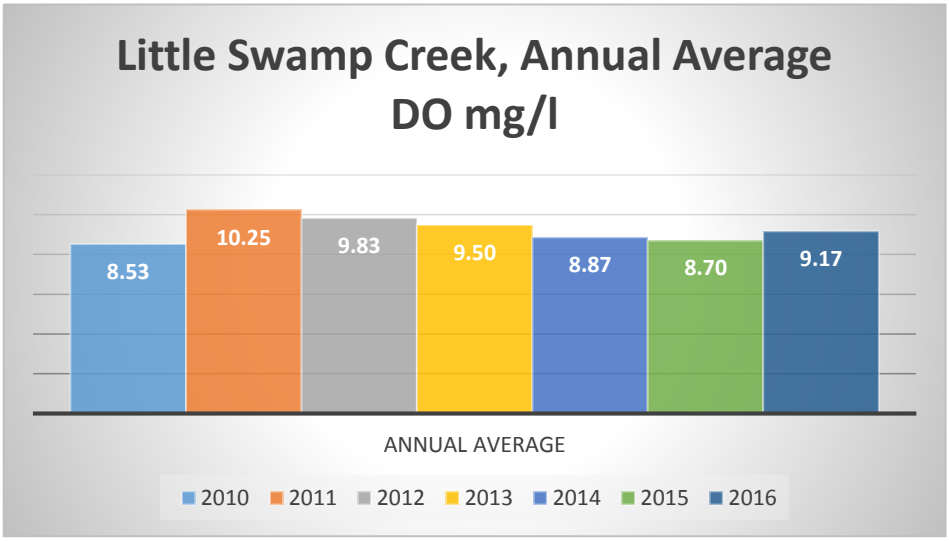

Figure 13. Little Swamp Creek annual average dissolved oxygen mg/l by year.

Temperature

Stream temperature data are limited to once a month ambient samples. Temperatures typically exceeded 16 degrees Celsius in the summertime, July into September. The warmest temperature measured was 19 degrees Celsius in July of 2015.

Conductivity

Conductivity levels indicate storm water runoff containing dissolved metals. Though the precise source of the metals is uncertain, it likely comes from upstream roads and parking lot runoff. There was a trend of decreasing conductivity from 2010 to 2013. Since 2013 the trend reversed and increased until 2015.

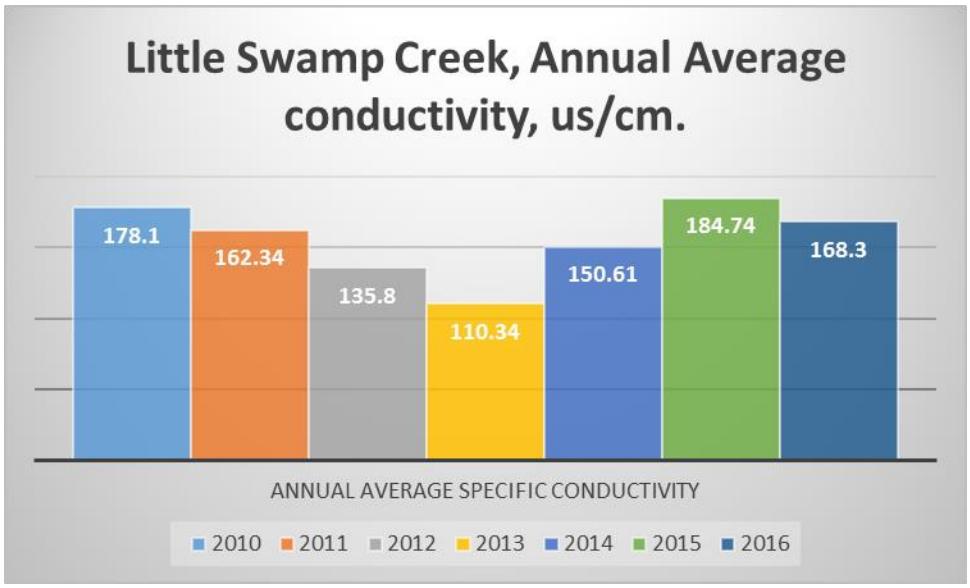

Figure 14. Little Swamp Creek conductivity us/cm by year.

pH

Values of pH are within the normal range for state water quality standards. There were observed fluctuations between years, but no discernible trend. The lowest value recorded was pH 6.61 in November of 2016.

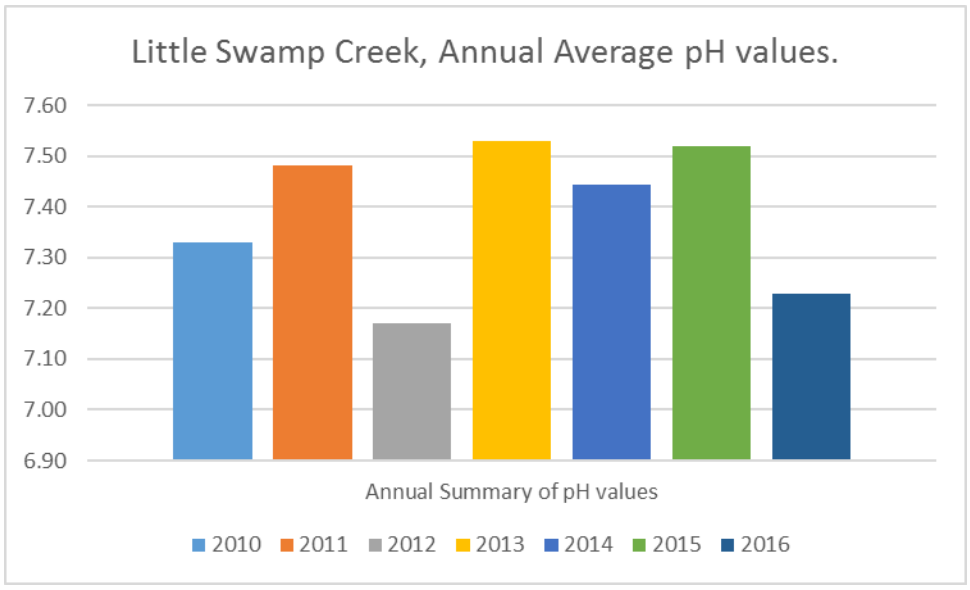

Figure 15. Little Swamp Creek pH values by year.

Bioassessment

No bioassessments were conducted in Little Swamp Creek SWMA.

Discussion

The dominant signals observed in the Little Swamp Creek watershed are low dissolved oxygen, high conductivity, and decreasing trend in pH. Typically the causes of said conditions are from urban development and inadequately treated storm water runoff.

Waynita Creek SWMA Results

Ambient Monitoring

One sample station was established on Waynita Creek. It is located just upstream of Wayne's Golf course off of Waynita Way. The site has been monitored since 2010 with ambient monthly sampling, long term stream temperature loggers, and bioassessments every three years.

Dissolved Oxygen

Generally dissolved oxygen (DO) levels were within state standards. In 2015 the annual average dipped slightly below the state standard of 9.5 mg/l. Minimum monthly levels observed since 2010 never dropped below 8.3 mg/l. The trend over time was one of a slight decrease in DO levels.

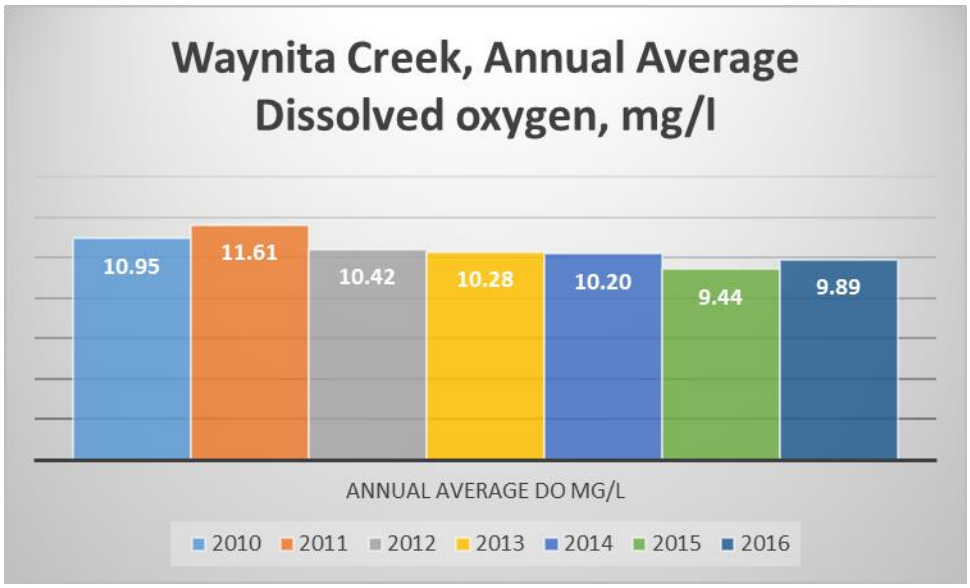

Figure 16. Waynita Creek annual average dissolved oxygen mg/l by year.

Temperature

Stream temperature was monitored using an instream temperature data logger since 2011. Waynita Creek had the highest percentage of days 26 percent, in 2015, exceeding state standards of a seven-day running average of > 16 degrees Celsius (C). This occurred during record warm air temperatures recorded for the region. The highest single temperature recorded was 19.87 degrees C in July of 2015. These high temperatures can impact aquatic biota, especially rearing juvenile salmonids.

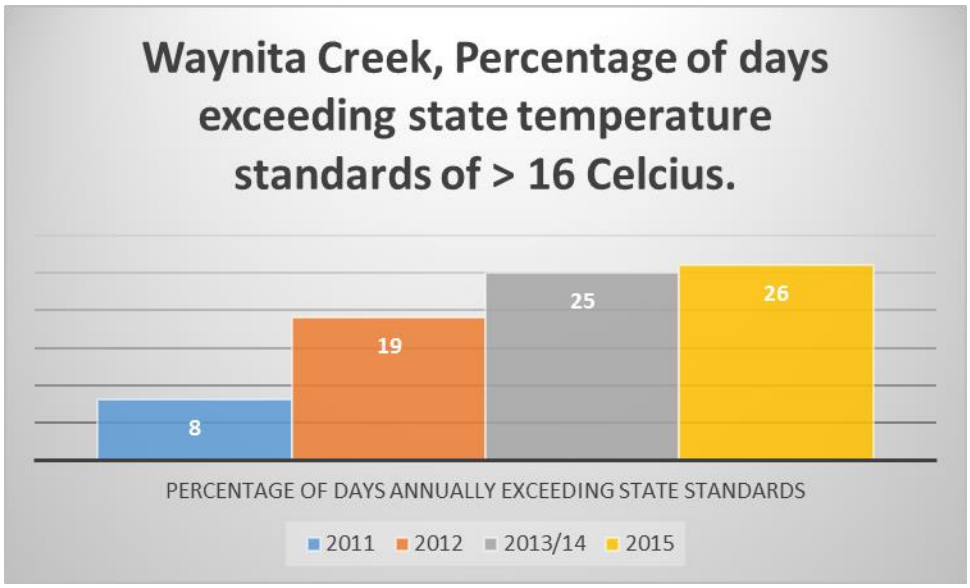

Figure 17. Waynita Creek annual number of days exceeding > 16 degrees Celsius state temperature standards.

Conductivity

Waynita Creek is second only to Parr Creek for high conductivity levels. Conductivity levels over the years have hovered around 242 us/cm. The high conductivity levels indicate potentially unhealthy conditions for aquatic biota.

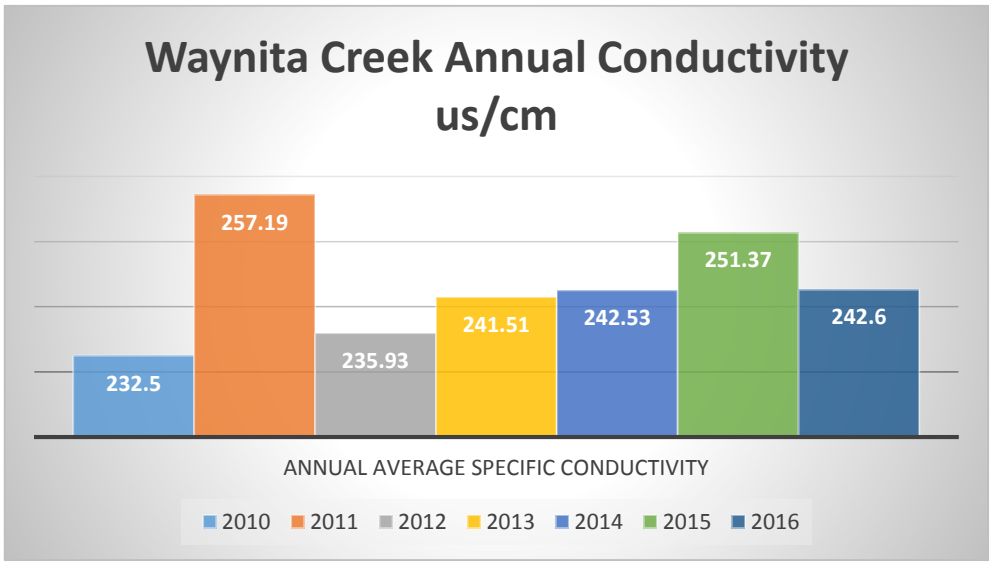

Figure 18. Waynita Creek conductivity us/cm by year.

pH

Values of pH in Waynita Creek follow the trends of other city watersheds. No exceedance of state standards were recorded since sampling began in 2010. The overall trend since 2010 has been a decrease in pH indicating acidification of the waters.

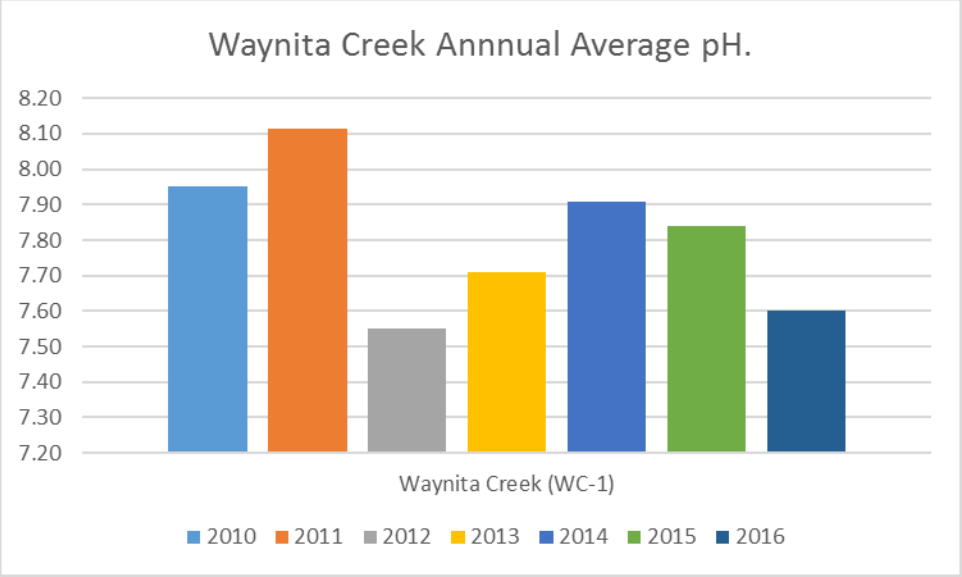

Figure 19. Waynita Creek pH values by year.

Bioassessements

Waynita Creek received bioassessments in 2010, 2013, and 2016.

Habitat - Wood

Surveys of the instream habitat measured in quantity of pools, depth of pools, and pool surface area found little change over the years. In survey year 2013 pool conditions, expressed as percentage of pool area ranked as fair. In 2016 it dropped back to poor the same as 2010. Frequency of large wood within the bankfull width and wetted width were poor for all three years. While the canopy closure is high, at 96 percent, little of it is translating into fallen wood into the channel. One piece of large wood was noted in 2016 that was from an electric power pole that had fallen into the channel.

Sediment

Stream substrate measures found remarkable shifts in sediment size as measured by percentage of sediment less than 2 mm. In 2010 it was 23 percent then dropped to 7 percent in 2013 and increased significantly to 40 percent in 2016. The watershed has several large erosion landslide hazard areas that episodically erode or fail and release large volumes of sediment into the channel upstream of the sample station.

Fish

Surveys of fish found three native species and no non-native species. Native species encountered included cutthroat trout, coho, and reticulate scuplins. Two juvenile coho were found in 2013 and two adult cutthroats in 2010. In 2016 two adult cutthroat were seen but not captured for detailed assessment. The fish assemblage scores a 3 out of 5 for all three years.

Stream insects

The trend in Waynita Creek's stream insects, Table 5, has seen an overall decline in health. The number of taxa has declined, there was a complete loss of mayflies, and a large increase in the percentage of tolerant taxa. One improvement has been the number of long lived taxa over the study period.

Table 5. Waynita Creek's metrics and B-IBI scores.

	Waynita Creek		
Year	**2010**	**2013**	**2016**
METRIC VALUES			
Taxa richness	28	29	19
E richness	3	2	0
P richness	4	5	3
T richness	1	5	2
Intolerant taxa richness	0	1	0
Clinger richness	11	13	10
LL richness	4	3	5
% tolerant	2.07%	5.66%	28.42%
% predator	6.56%	12.26%	33.68%
% dominance (3)	56.82%	63.58%	64.21%
B-IBI Score	**24**	**28**	**22**

Special Note

Flows in Waynita Creek have had a noticeable change since 2010. Based on bioassessment data, summer low flows decreased by an estimated 95 percent from 2013 to 2016. Flows for all other sites remained relatively unchanged or experienced an increase in flows for this same time period. A possible cause for the change might be linked to a large single family housing development that was built in 2015. The storm water runoff from the site has been diverted out of Waynita Creek watershed with a direct discharge to the Sammamish River.

Discussion

The various signals observed in Waynita Creek SWMA are of overall poor aquatic health condition. Causes include lack of diverse instream habitat, high conductivity, high fines in stream substrate, flow changes, and high stream temperatures. Fish diversity indicates potential to afford refuge to salmonids and other native species. Stream insects have shown a decline in diversity and health.

Its upper watershed is urbanized but no more so than most other watersheds in the city. The high conductivity levels may be due to natural geologic parent material in the watershed leaching out metal ions through groundwater flows into the creek.

Queensborough SWMA Results

In the Queensborough SWMA, two stations were sampled. One on the lower reach of Queensborough Creek,CQ-1 and the other on Perry Creek, PR-1, just downstream of 228th Avenue. Perry Creek has a separate sampling location for fecal coliform bacteria near its confluence with North Creek. The two ambient monitoring stations have been monitored since 2010 and each received bioassessments in 2010, 2013, and 2016. Temperature loggers have been deployed during various periods of time in both streams.

Ambient Monitoring

Dissolved Oxygen

Dissolved oxygen levels at both sample stations tended to meet state standards with few exceptions that occurred in 2014 and 2015. The lowest monthly reading was in August of 2015 of 8.2 mg/l for QC-1 and 6.64 mg/l in July 2014 for Perry Creek.

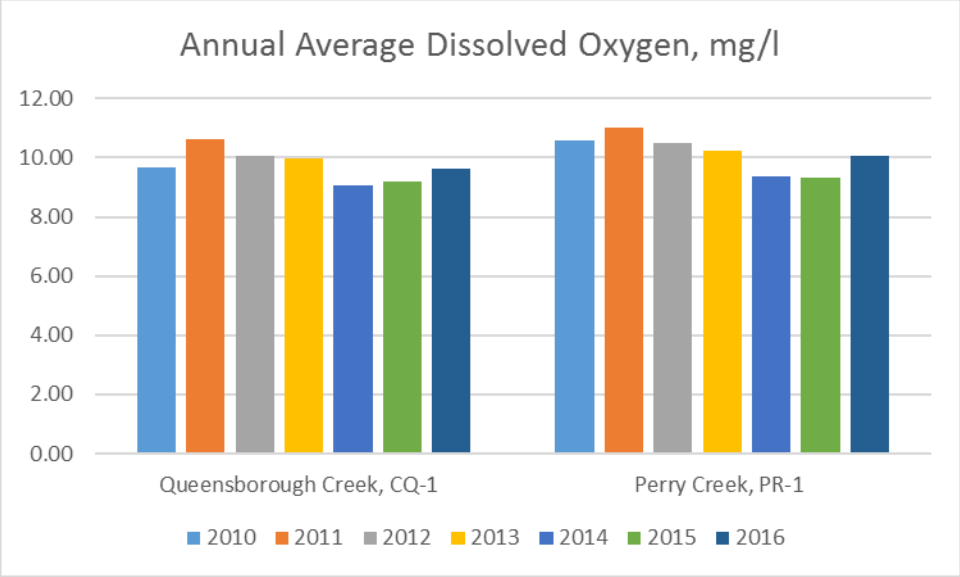

Figure 20. Queensborough and Perry Creek dissolved oxygen, mg/l by year.

Temperature

The most complete set of continuous stream temperature is from Queensborough Creek. Perry Creek had data from 2010 and early 2011. In the following years, equipment failure caused no data to be collected. The highest temperature encountered in Queensborough Creek was 20.98 degrees Celsius in July of 2015. A temperature of 21 can create migration barriers to upstream migrating adult salmon. The year 2015 had the highest number of days not meeting state standards for the three-year comparison.

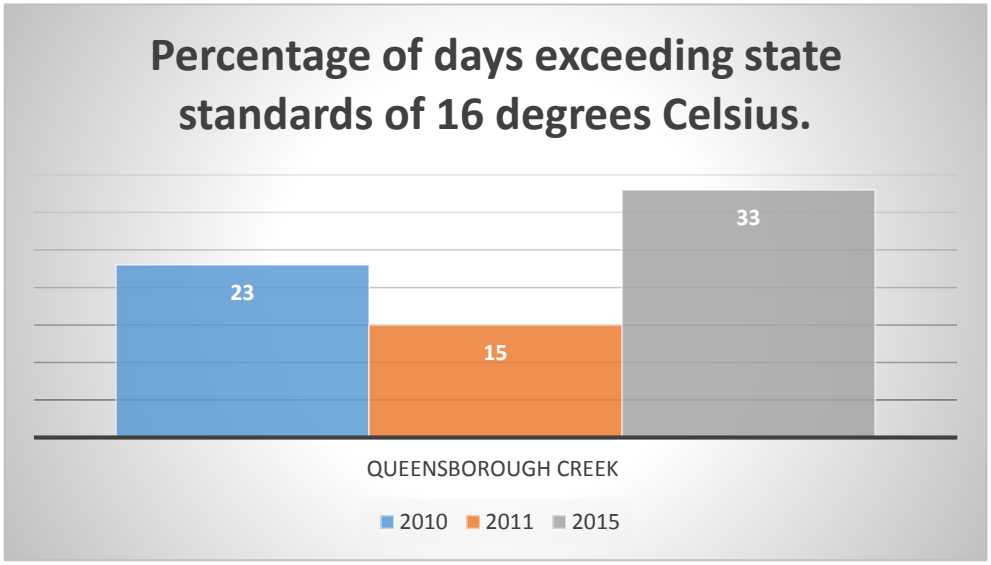

Figure 21. Queensborough Creek percentage of days exceeding state temperature standards seven-day running average of > 16 degrees Celsius.

Conductivity

The annual average conductivity levels were typically higher in Perry Creek.

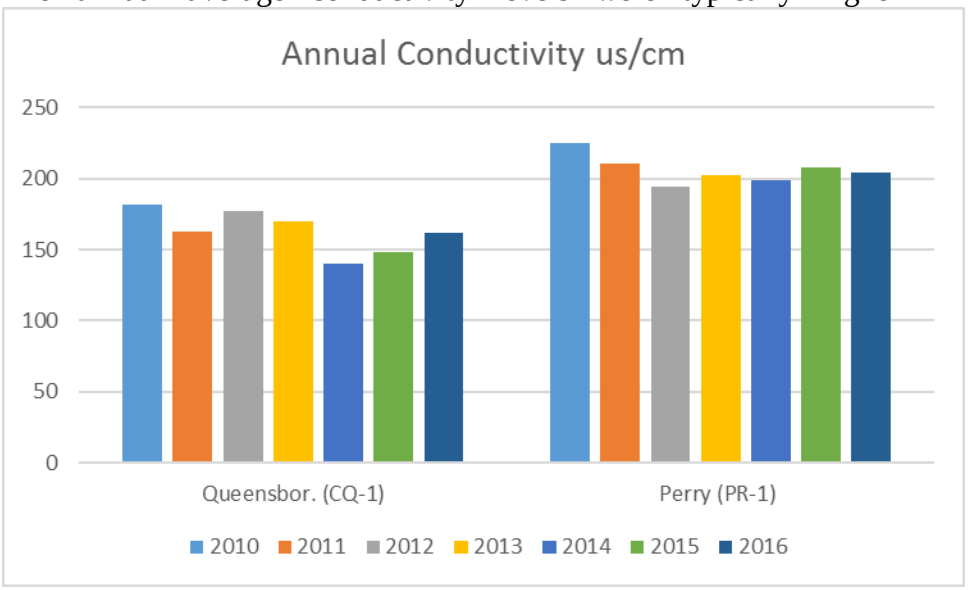

Figure 22. Queensborough and Perry Creek specific conductivity us/cm by year.

pH

The pH values mirrored conductivity with Perry Creek having higher overall pH values than Queensborough Creek. On two occasions, March 2013 and February 2016, Queesnborough Creek's pH value was below state standard of 6.5 with 6.47 and 6.24 respectively. Perry Creek has never had a pH value below or above state standards.

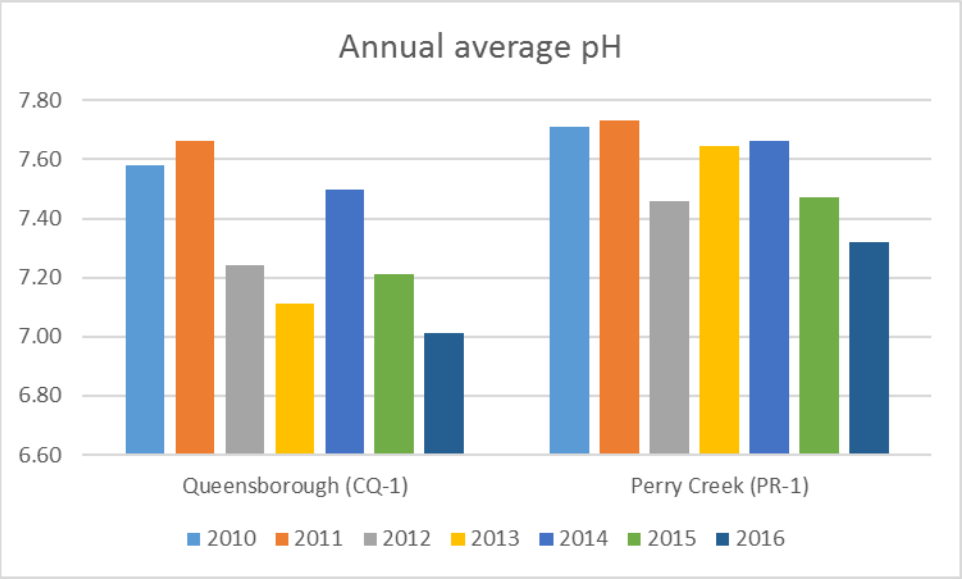

Figure 23. Queensborough and Perry Creek pH values by year.

Bioassessments

Each stream received bioassessments in 2010, 2013, and 2016.

Habitat – Wood

Instream pool habitat for both has rated as poor during all three years. Queensborough had no pools and Perry Creek's pool surface area dropped all three years from 22 percent down to 14 percent. Large wood counts in all years for both sites found no large wood. The riparian corridor, while well shaded, upwards to 90 Percent, trees tended to be young red alders or extensive blackberry patches. Hence, future recruitment of large wood appears to be limited or nonexistent.

Sediment

Fine sediment dominates both streams. Perry Creek has seen an increase in accumulated fines, < 2mm, from 20 percent in 2010 to 31 percent in 2016. Queensborough has seen up to 52 percent fines in 2013 to 36 percent fines in 2016. At these levels, the fines are having a negative impact on stream insects and fish productivity.

Fish

Queensborough has seen its fish diversity drop off. In 2010, three salmonid age classes were present but by 2016 only one was left. Reticulate sculpins were observed in 2010 and have not been seen since. Perry Creek's fish diversity has remained nearly identical throughout the survey years. Young cutthroat trout with at least two age classes being present. The reticulate sculpins have not been observed in Perry Creek. Western brook lamprey were observed in both streams in 2013 and only in Perry Creek in 2010. The low diversity for both streams are indicative of the general lack of habitat and poor water quality conditions.

Stream Insects

Perry Creek's benthic index of biological integrity (B-IBI) increased slightly in 2016, whereas Queensborough Creek had a decline in B-IBI scores. Both had slight increases in taxa richness, number of species present, and low intolerant taxa numbers. They each had a high percentage of their dominant taxa represented by just three taxa, indicating a decline in diversity health. In 2016 the replicate sample for Perry Creek returned a B-IBI score of 22, whereas the sample scored a B-IBI of 24. This difference is negligible and indicates little to no change in the B-IBI score since 2010.

Table 6. Perry and Queensborough Creek's metrics and B-IBI scores.

	Perry Creek			**Queensborough Creek**		
Year	**2010**	**2013**	**2016**	**2010**	**2013**	**2016**
METRIC VALUES						
Taxa richness	29	30	33	29	25	32
E richness	2	2	2	2	1	1
P richness	3	4	3	3	2	2
T richness	4	4	3	1	1	3
Intolerant taxa richness	0	0	1	0	0	0
Clinger richness	13	11	11	10	7	10
LL richness	4	2	4	4	3	3
% tolerant	6.13%	0.99%	5.36%	2.77%	0.83%	0.50%
% predator	4.28%	4.11%	12.10%	10.55%	13.72%	8.65%
% dominance (3)	50.56%	62.01%	64.29%	61.94%	52.18%	67.55%
B-IBI Score	**22**	**22**	**24**	**22**	**22**	**20**

Discussion

The various signals observed in Queensboroough SWMA are of overall poor aquatic health. Causes include: lack of diverse instream habitat, high conductivity, high fines in stream substrate, lack of instream large wood, and high stream temperatures. These impacts are the result of urban land uses that inadequately treat storm water runoff, ineffective protection of streams, wetlands, and their buffers. Perry Creek drains a higher percentage of commercial land use of about 10 percent, whereas 83 percent of Queensborough Creek is dominated by single family residential land use. Perry Creek contains more than twice the length of piped drainage at 22 miles, whereas Queensborough Creek has 10 miles. These differences in land use most likely contribute to the differences in conductivity levels but have similar influence on overall stream health.

Canyon Park SWMA Results

The primary sample location is at Junco Creek just upstream of 228th Avenue. Other streams previously monitored include Middle Creek and Maltby Hill Creek. Middle Creek had bioassessments performed in 2010 and 2013. There exists multiyear stream

temperature data on Middle Creek (Loch, 2014). No continuous stream temperature loggers were ever deployed in Junco Creek. It received bioassessments in 2010, 2013, 2016. Junco Creek is a long-term monitoring site for fecal coliform bacteria. Results of fecal coliform bacteria monitoring can be found in annual reports City of Bothell, 2017.

Junco Creek

Dissolved Oxygen

Annual average dissolved oxygen levels decreased from 2011 to 2015. The annual average failed to meet state standards, of not < 9.5 mg/l, from 2013 through 2016. In 2016 the levels increased over 2015 but not above state standards.

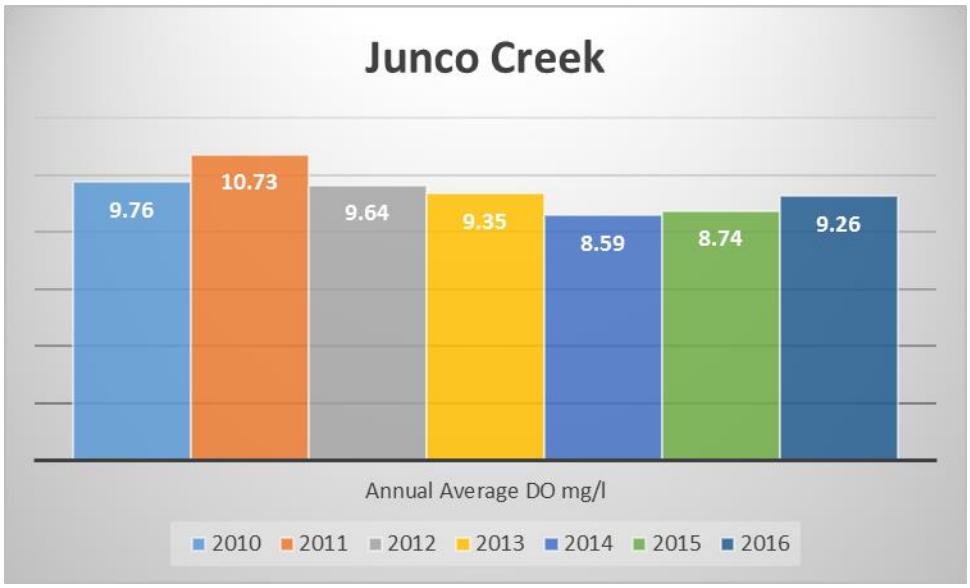

Figure 24. Junco Creek dissolved oxygen mg/l by year.

Temperature

Stream temperatures were collected during once per month ambient monitoring. Temperatures always met state standard of not to exceed 16 degrees Celsius in summer time, July through September. The warmest temperature recorded was 16 degrees Celsius in July 2015.

Conductivity

Conductivity levels were fairly consistent throughout the study period. Notable exceptions were in 2010 and 2015 when levels were relatively lower than all other years. The conductivity levels do indicate storm water runoff containing higher than natural background levels of dissolved metal ions.

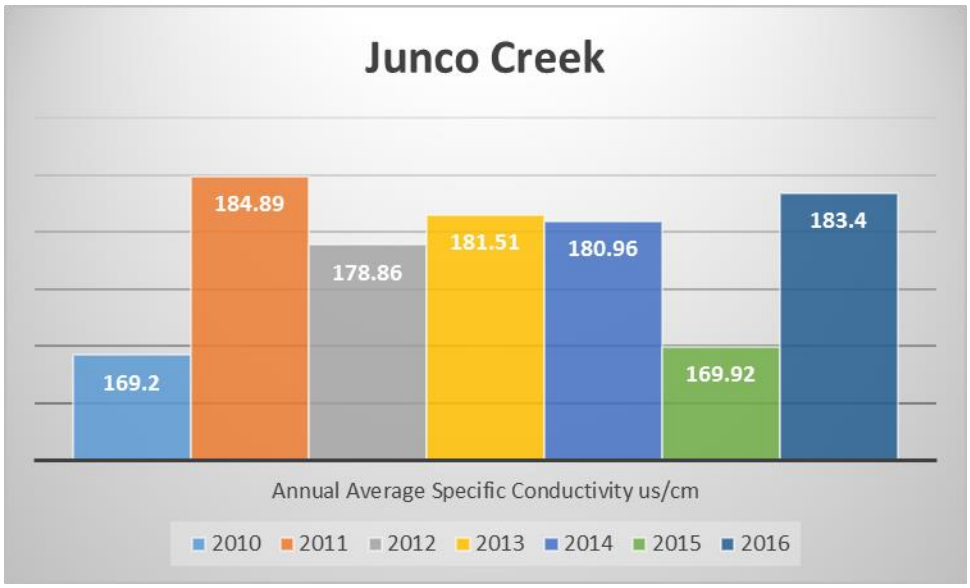

Figure 25. Junco Creek specific conductivity us/cm by year.

pH

Values of pH in Junco Creek have seen a decline since 2010. At no time have pH levels dropped below or above state standards, pH > 6.5 and < 8.5.

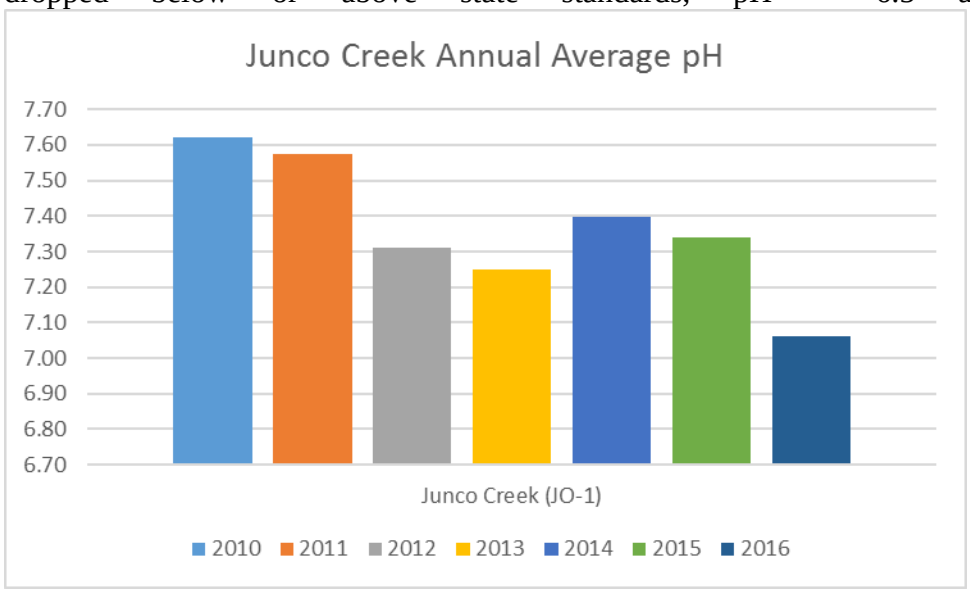

Figure 26. Junco Creek pH values by year.

Bioassessments

Junco Creek received bioassessments in 2010, 2013, and 2016.

Habitat – Wood

Junco Creek sample station is located within a restoration project that occurred in early 2000s. Restoration included streambank plantings, creation of a new stream channel, installation of wood, and placement of streambed gravel.

The pool habitat was ranked as poor for all three survey years. In 2010 and 2016 no pools were identified and two were identified in 2013. Anecdotal observations have noted that much of the habitat in Junco Creek is of a glide type with multiple deep pool like scour points but no pool tailouts with shallow enough depths to allow the scour feature to count as being a pool. Large wood was present due to the restoration efforts to place large wood into the channel. Seven pieces were found to be within the wetted channel. The riparian buffer is still young immature trees and it will be decades before natural recruitment of wood will be realized for this stream reach.

Sediment

Sediment surveys found low levels of fines, less than 2 mm. Levels of fines greater than 15 percent are considered harmful to aquatic biota. Junco had levels of fine at or below the 15 percent threshold. This indicates that upstream sources of fines are low and that the stream channel is not aggressively eroding its banks. Monthly flow observations have noted that flows tend to be fairly consistent throughout the year, indicating stable hydrology in the upper watershed.

Fish

Fish surveys found cutthroat trout to be the dominant species. Other fish species found were native reticulate sculpins and long nose dace. Reticulate sculpins showed an increase from 2010 to 2016 in numbers and age classes present, whereas cutthroat trout age classes decreased from three to two. Overall, the fish diversity was low.

Stream Insects

Table 7. Junco Creek's metrics and B-IBI scores.

	Junco Creek		
Year	**2010**	**2013**	**2016**
METRIC VALUES			
Taxa richness	27	33	24
E richness	2	3	0
P richness	3	1	1
T richness	4	6	8
Intolerant taxa richness	2	1	0
Clinger richness	9	11	11
LL richness	2	2	2
% tolerant	14.00%	7.98%	14.29%
% predator	3.00%	3.90%	31.25%
% dominance (3)	55.60%	57.98%	37.50%
B-IBI Score	**18**	**22**	**28**

The trend over time has been one of improving benthic index of biological integrity since 2010, Table 7. There has been a decline in dominance by just three taxa, an increase in caddis flies and percent predators. This indicates a diverse habitat for instream insects and their different feeding strategies. A few noted exceptions to improvement are the loss of mayflies and an increase in the percentage of tolerant taxa to polluted waters.

Discussion

Junco Creek sample station revealed relatively stable flows and low sediment inputs. Its overall health is ranked as poor due to low wood frequency, poor aquatic habitat, and high stream temperature. The decline in pH values indicates a potential change in upstream water acidity, but the source of the change is unknown. This trend of declining pH values has been seen at most other sampling locations within the city. Its improvement in B-IBI score indicates a progression towards healthier instream habitat while water quality continues to decline. Stable flows are its best asset that potentially ameliorates some stresses that are occurring due to urban development.

Middle Creek Results

Middle Creek's sampling station is located in the center of the Canyon Park Business Center. It is upstream of a large wetland complex that flows into North Creek. It flows primarily along road right-a-way and is heavily landscaped with manicured lawns and sparsely spaced trees along sidewalks. Middle Creek was removed from the study in 2015. The reason for dropping it was the need to add new sites while not increasing the workload to collect and analyze the data for the study.

Dissolved Oxygen

Dissolve oxygen levels in Middle Creek have been in decline since 2011. Out of the six years of monitoring, only one year, 2011, met state water quality standards for dissolved oxygen. Lowest readings tend to occur late summer into early autumn.

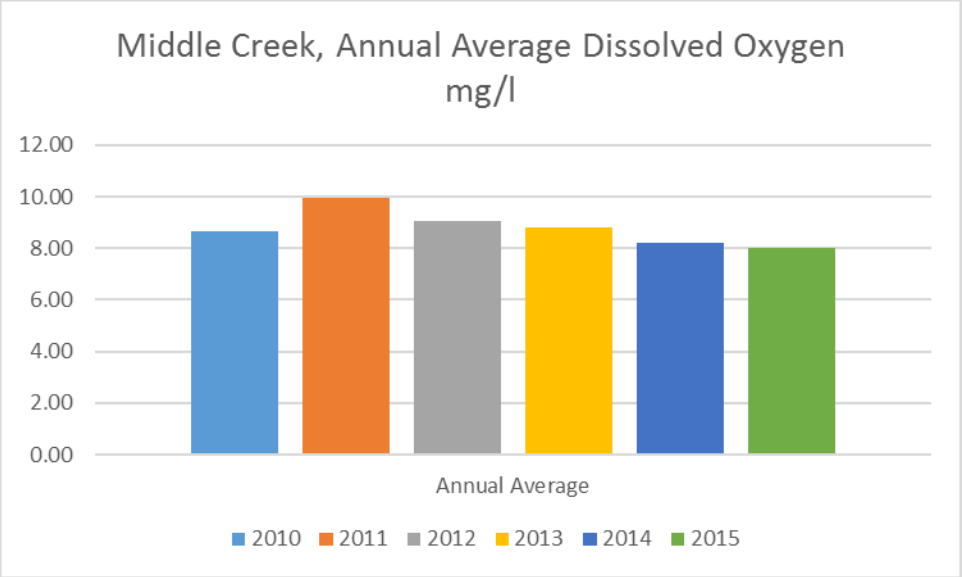

Figure 27. Middle Creek annual average dissolved Oxygen mg/l.

Temperature

Stream temperatures in Middle Creek were warmest in 2015 with the highest single maximum temperature recorded at 21.96 degrees Celsius in August. These levels are

generally considered to be migration barriers to salmonids. Other impacts at these temperatures are thermal stress on fish that can lead to disease outbreaks and infections.

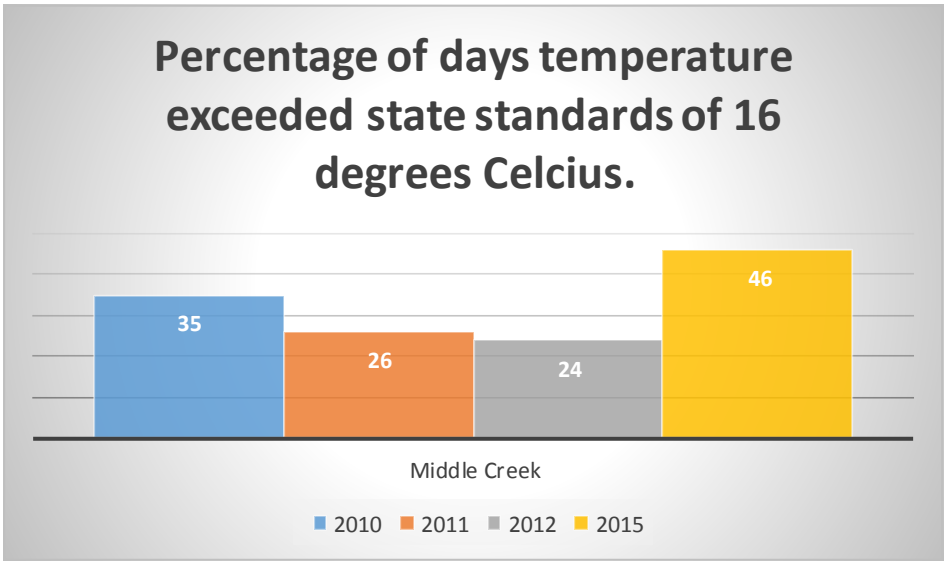

Figure 28. Middle Creek, percentage of days temperature exceeded state standards.

Conductivity

Over time, Middle Creek's conductivity declined from 2010 to 2015. This indicates a decrease in dissolved metal ions in the water. Dissolved metals often are attributed to untreated storm water discharges. The decline could indicate a real change in source of flows in the stream.

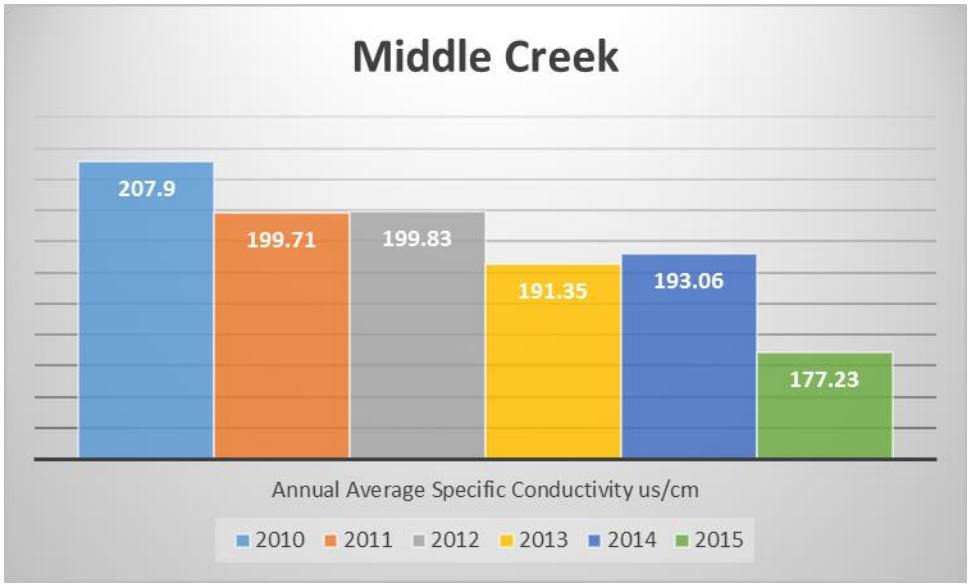

Figure 29. Middle Creek annual average specific conductivity.

pH

The trend over time was a decline in pH levels. This was a trend observed in most other streams. The pH values never exceeded state standards.

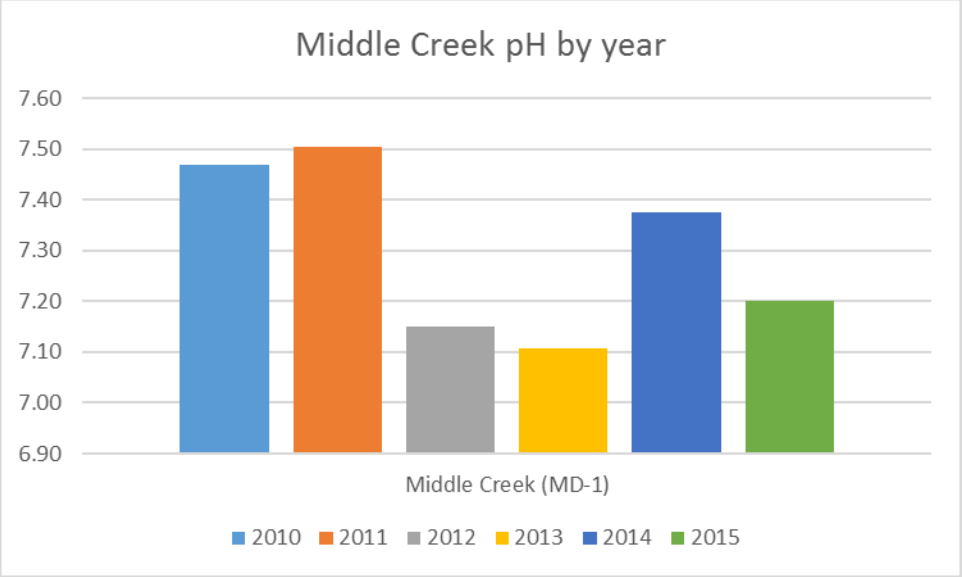

Figure 30. Middle Creek annual average pH by year.

Bioassessment

Middle Creek received bioassessments in 2010 and 2013.

Habitat – Wood

The pool habitat was ranked as poor in 2010 and 2013. One pool was recorded in each year and represented about 13 percent of wetted surface area. Large wood was absent in both survey years. The riparian buffer consisted of road, sidewalk and some low-growing shrubs. It had one of the lowest canopy closure of all streams at 30 percent and 46 percent in 2010 and 2013, respectively. There is no potential for future natural recruitment of large wood into the stream.

Sediment

Sediment surveys found high levels of fines of less than 2 mm. In 2010 they were at 41 percent and in 2016 at 39 percent. Levels of fines greater than 15 percent are considered harmful to aquatic biota. Middle Creek had some of the highest levels observed within sampled city streams.

Fish

Fish surveys in 2010 observed native three spine stickle backs to dominate the fish assemblage. A non-native minnow was the only other species observed in 2010. In 2013, the assemblage was dominated by non-native species that included weather loach, sunfish, and minnows. Three spine stickle backs were the only native species observed. This change in fish species composition represents a potential for the spread of more non-native species to North Creek and its tributaries. Middle Creek ranked low for fish diversity in both years.

Stream Insects

The results for Middle Creek showed low in-stream health conditions for stream insects. Between 2010 and 2013, nine out of ten metrics of health declined. Affected metrics included taxa richness, measure of diversity, loss of intolerant taxa, loss of predator taxa, and an increase of tolerant taxa, those that survive poor water quality conditions. In 2010 and 2013 blackfly larvae, *Simulium*, were the dominant species. Blackfly larvae abundance typically indicates heavy nutrient enrichment. They are collector filter feeders using sticky hair-like fans. They represent more generalist species, as opposed to those which require special foods or particular types of physical habitat.

Discussion

The common signals of aquatic health in Middle Creek were high stream temperatures, high fine sediment loading, low dissolved oxygen, presence of abundant non-native fish species, poor instream habitat, and negative influences of storm water runoff. Relative to all other streams surveyed, Middle Creek had the lowest scores for stream health.

Fitzgerald SWMA Results

The primary sample location in Fitzgerald SWMA is Palm Creek (PM-1). Woods Creek was monitored for several years but then discontinued in 2014. Results of Woods Creek monitoring are available in Loch, 2011 and 2012. The sample station on Palm Creek is located downstream of its crossing under 228th Avenue at the Whole Earth Montessori School. It has been monitored since 2010 with nearly continuous stream temperature loggers.

Dissolved Oxygen

Palm Creek's dissolved oxygen had been in steady decline since 2011 but did increase in 2016. Periodically dissolved oxygen levels dipped slightly below state standard of > 9.5 mg/lduring either summer low flow or early-to-mid autumn in 2012, 2014, and 2015.

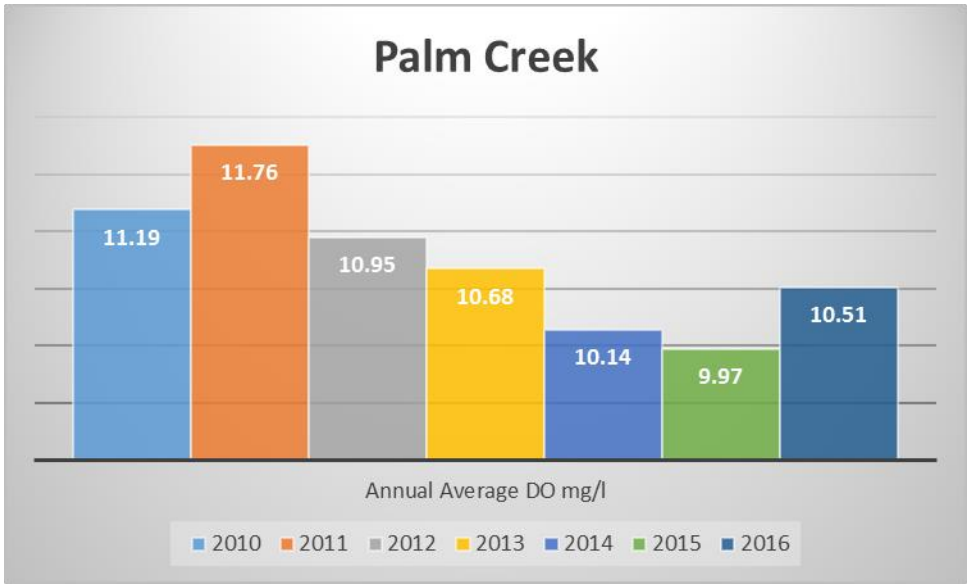

Figure 31. Palm Creek dissolved oxygen mg/l by year.

Temperature

Temperature loggers were deployed between 2010 and 2016. There were several periods when the loggers failed to record data. Four summer periods were captured as well as two nearly complete years of temperature data. Temperatures always met state temperature standards for a seven-day running average of not more than 16 degrees Celsius. Seven-day running averages did record 13 days above the 13 degree Celsius state standard, eleven days in 2013, and two days in 2014.

Conductivity

Levels of conductivity remained fairly consistent throughout the years. There were fluctuations between years with no discernable trend. These levels indicate storm water runoff containing higher than natural background levels of dissolved metal ions.

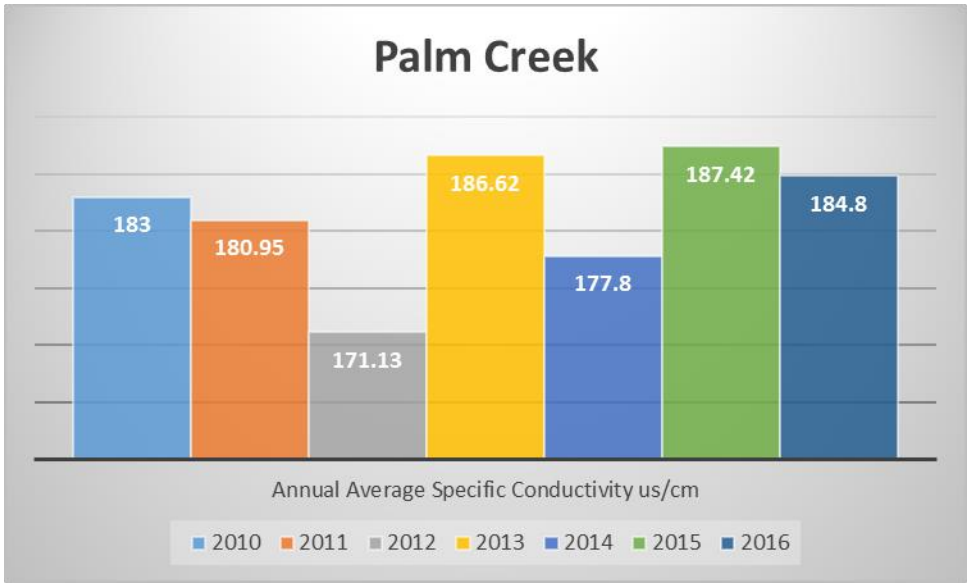

Figure 32. Palm Creek specific conductivity us/cm by year.

pH

Palm Creek's pH level has declined over time from 2010 to 2016. At no time have pH levels dropped below or above state standards, pH > 6.5 and < 8.5. The decline in pH values indicates a potential change in upstream water acidity but the source of the change is unknown. This trend of declining pH values has been seen at most other sampling locations within the city.

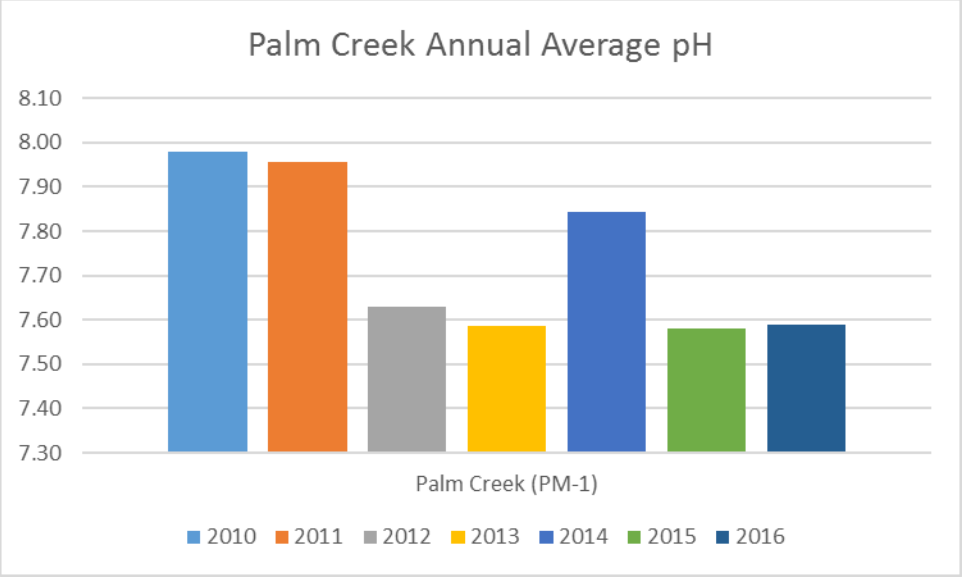

Figure 33. Palm Creek pH values by year.

Bioassessments

Habitat – Wood

Pool habitat was nearly absent in the stream. Pool area tended to account for no more than 7 percent of the wetted surface area. Large wood was present in low quantities, no more than two pieces in any given year. The riparian zone has recently been planted with native plants, shrubs and small trees. Natural recruitment of large wood is decades away. Pool habitat and large wood conditions was ranked poor in all three survey years.

Sediment

Percent of fines < 2 mm were above the targeted condition of not more than 15 percent. In 2010 fines were 39 percent, in 2013 20 percent and in 2016 27 percent. At these levels, the fines are having a negative impact on stream insects and fish productivity.

Fish

Fish surveys found cutthroat trout to be the dominant species. One other native fish species, reticulate sculpin, was the only other fish species in Palm Creek. Reticulate sculpins showed an increase from 2010 to 2016 in numbers and age classes present, whereas Cutthroat trout age classes increased from two to three. Overall the fish diversity was moderate in all three years.

Stream Insects

Table 8. Palm Creek's metrics and B-IBI scores.

	Palm Creek		
Year	**2010**	**2013**	**2016**
METRIC VALUES			
Taxa richness	26	32	44

E richness	2	1	2
P richness	4	7	6
T richness	5	5	8
Intolerant taxa richness	0	2	1
Clinger richness	11	15	18
LL richness	1	4	6
% tolerant	3.31%	0.00%	0.28%
% predator	9.36%	14.52%	12.71%
% dominance (3)	53.02%	57.26%	42.37%
B-IBI Score	**24**	**28**	34

The trend over time has been one of improving benthic index of biological integrity (B-IBI) since 2010. Improvements were noted in number of taxa present with decrease in the three dominant taxa. Long-lived taxa increase steadily over time. Slight declines were measured in number of tolerant taxa. The B-IBI score has improved, yet its classification has remained unchanged since 2013 at moderately impaired. In 2010 it was classified as severely impaired.

Discussion

Palm Creek has cool water temperature and well oxygenated waters. It has high levels of dissolved metals and fine sediment, and a lack of large wood in channel. Its pH has been decreasing over the length of the study period. The aquatic biota for Palm Creek ranks as best in the city. However, it exhibits indicators of susceptibility to the negative effects from urban development as expressed in fish and stream insect diversity.

Juanita SWMA Results

Juanita creek is a new addition to the monitoring program in 2016. The upper headwaters to Juanita Creek were annexed into the City in 2013. One sample station was established near the City's southern boundary at 145th Street and Juanita Woodinville Way. This stream flows directly into Lake Washington.

Ambient monitoring results for 2016 found low dissolved oxygen not meeting state standards, stream temperatures at or slightly above state standards, and high conductivity. Visual observations of the channel saw high levels fine sediment, no large wood, and the channel itself runs parallel to Juanita Woodinville Way NE for about 2,000 feet.

North Creek

North Creek's watershed is split between multiple SWMAs. At each sample station, NC-1 and NCLD, one bank of the stream is in one SWMA and the opposite bank lies within a different SWMA. North Creek's sample results are separated out here for reporting purposes only. There are two sample stations on the main stem of North Creek. A downstream sample station, NC-1, was located just upstream of State Route 522. An upstream station, NCLD, was located just upstream of the 240th Street Bridge and has been monitored since 2015. Snohomish County had been monitoring the site as part of their TMDL program for over ten years. In 2012 and 2013 a sampling station, NC-2, was established at the northern most upstream reach of North Creek within the city at State Route 524 Bridge. This site was discussed in previous monitoring reports. This report of results will limit itself to NC-1 and NCLD. NCLD is a sample site for the collection of fecal bacteria data. The fecal bacteria data is discussed in Loch, 2017 in the annual TMDL North Creek study.

Dissolved Oxygen

From 2011 to 2015, annual average dissolved oxygen decreased at the downstream sample station, NC-1. This parallels an increase in stream temperature during this time. It reversed course in 2016 with a slight increase but still below the state water quality standard of not less than 9.5 mg/l. At the upstream location, dissolved oxygen levels appear higher than at the downstream station. It, too, saw an increase in dissolved oxygen from 2015 to 2016. The longest stretch where NC-1 failed to meet state standards was in 2015 from June through November, a six-month period.

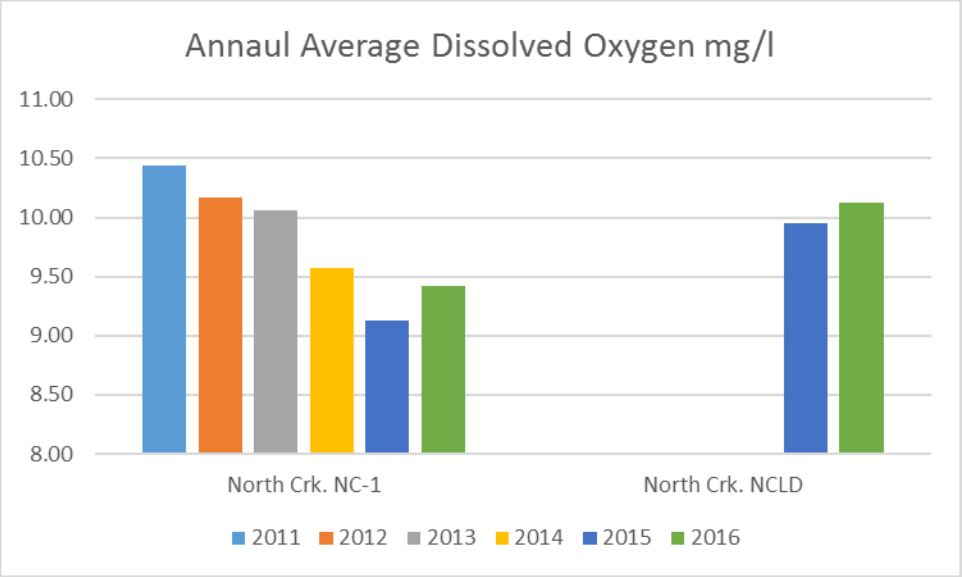

Figure 34. North Creek dissolved oxygen mg/l by year.

Temperature

There was a consistent increase from 2012 through 2014 in numbers of days that North Creek's seven-day running maximum stream temperature failed to meet state standards. In 2015 there was a decrease in days. This is unexpected since 2015 was overall one of the region's warmest summers with extreme low flows reported from gage stations. However, it had been noted in some regional monitoring of streams that the low summer flows were comprised of higher concentrations of groundwater inflows verses surface sources. This could explain why North Creek had, in general, lower stream temperatures during 2015. The highest recorded temperatures in North Creek occurred in July of 2013 at 22.37 degrees Celsius. Other Julys had similar high temperature readings. Monthly ambient temperature monitoring at NCLD upstream station recorded temperatures above the state standards from May into July.

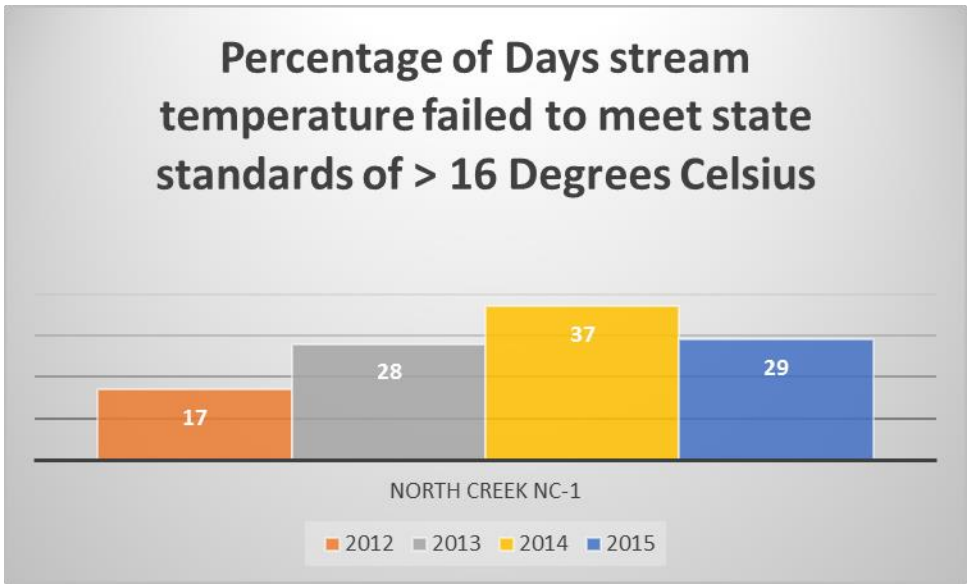

Figure 35. North Creek percentage of days stream temperature exceeded state standards.

Conductivity

The upstream station, NCLD, had slightly higher readings than downstream station, NC-1, of 169 and 161 us/cm in 2015 and 2016 respectively. Conductivity levels in North Creek remained relatively unchanged throughout the monitoring period from 2011 through 2016. These levels indicate higher than natural background levels and indicate urban storm water runoff is contributing to the higher amount of dissolved metal ions.

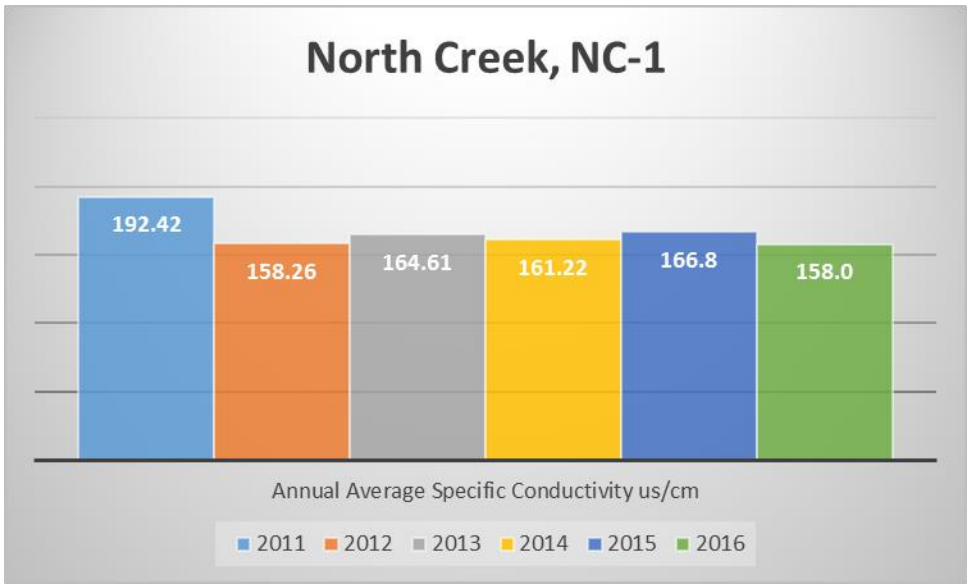

Figure 36. North Creek specific conductivity us/cm by year.

pH

Levels of pH at the downstream location in North Creek showed an overall trend of decreasing values from 2011 through 2016. At no time did it fail to meet state standards.

At the upstream location, NCLD for 2015 to 2016, a similar decrease in pH values was observed.

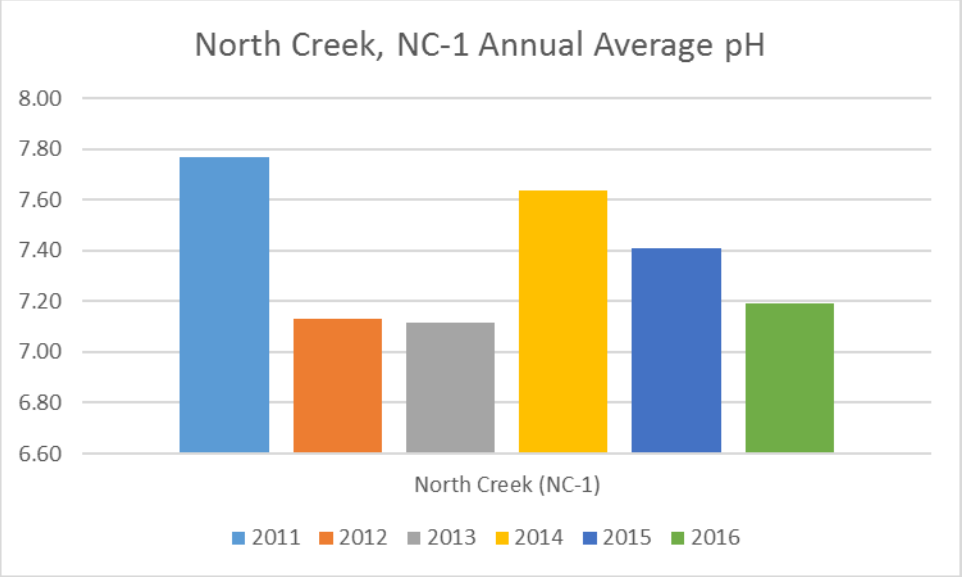

Figure 37. North Creek annual average pH values by year.

Bioassessments

No bioassessments were conducted in North Creek at either sample station.

Discussion

In general, water quality is of a higher standard upstream, NCLD, than it is at the downstream station, NC-1. Issues affecting both locations include: declining pH values, high stream temperatures, low dissolved oxygen levels, and high dissolved metals. North Creek drains a highly urbanized watershed and this is reflected in its poor water quality conditions.

All Sites Combined Monitoring Result for Study Period 2010 to 2016

Dissolved Oxygen (DO)

In general, all streams showed a similar pattern of decreasing dissolved oxygen since 2010 through 2015. Dissolved oxygen levels increased among all streams in 2016. As water warms it loses its capability to hold oxygen. Hence, dissolved oxygen levels are in part a result of ambient air temperature which in turn drives stream temperatures.

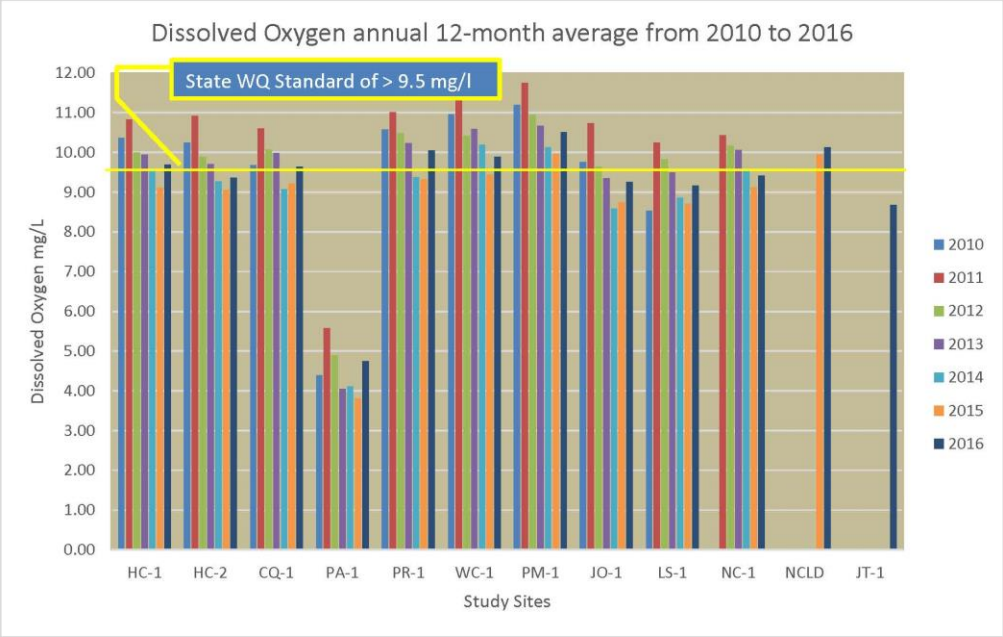

Figure 38. Dissolved oxygen for study sites from 2010 to 2016.

Parr Creek occasionally experienced lethal levels of low DO to salmonids. These levels often begin in late spring to early summer and last into the early part of autumn. At no time have dissolved oxygen levels ever met state water quality standards in Parr Creek at the lower stream station (PA-1). Middle Creek had one occurrence of lethal levels during August 2010. (Lethal level to salmonids is: < 3.3 mg/l, Spence et. al. 1996.)

Temperature Logger Data 2010 to 2015

Temperature loggers were deployed at various sites and for various time spans over the study period. The loggers measured stream temperature at 15-minute intervals. Several deployed loggers failed to record temperatures. Data was cropped pre-retrieval and post-deployment to establish nearly same start and finish times for all streams. This allowed direct comparison of logger data between all streams within any given year.

All streams tended to exceed WDOE standards during the summer except for Palm Creek (PM-1) which *never* exceeded WDOE standards throughout its recording period 2010 through 2011. Streams routinely met temperature standards for November and December.

The trend over time was one of increasing stream temperatures from 2011 through 2015. The highest recorded temperature for nearly all sites occurred in 2015 during one of the warmest periods recorded for the Puget Lowland ecoregion. Figure 39 is a composite of streams that had temperature logger data and the highest single recorded maximum temperature.

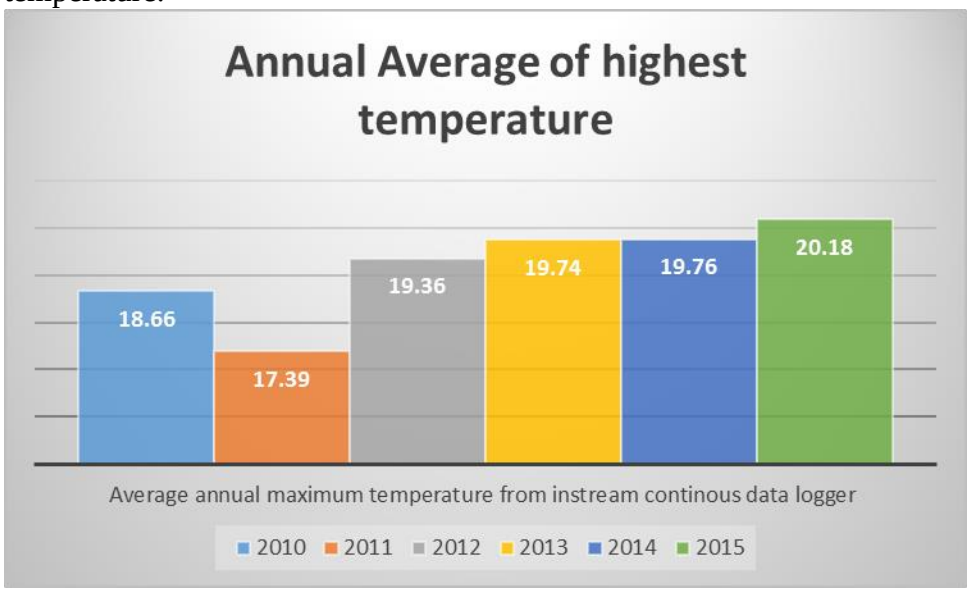

Figure 39. Stream temperature records for maximum temperature recorded for all sites by year.

Conductivity

Specific conductivity throughout the city was seasonally influenced. Highest readings occurred in the summer and lowest readings in late spring. The highest readings for specific conductivity occurred on Parr Creek's lower reach and at Waynita Creek. Figure 40 shows the between-year variability between sites and years. All sites generally followed the same pattern between years.

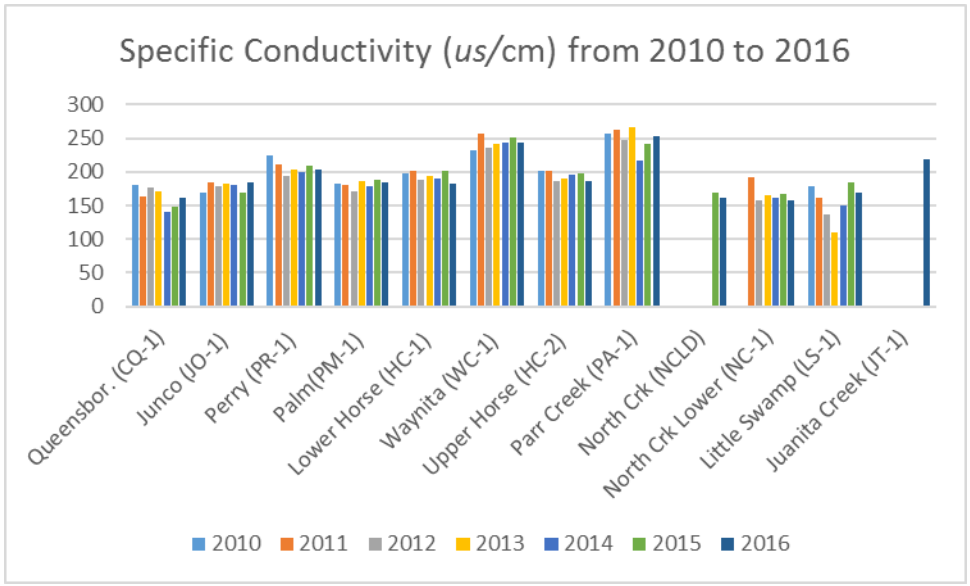

Figure 40. Annual average of stream-specific conductivity us/cm by stream and year.

pH

Values of pH followed the same seasonal trend as conductivity. In general most sites followed a similar year-on-year decrease in pH values. Since 2010 there has been an overall decline. Several sites have had readings below state water quality standard of > 6.5 and < 8.5. Parr Creek has seen pH values as low as 6 in 2016 and similar levels in 2013, 2012 and 2013. Other sites with periodic low pH values include upper Horse Creek and Queensborough Creek. A decrease in pH indicates stream water chemistry is becoming more acidic.

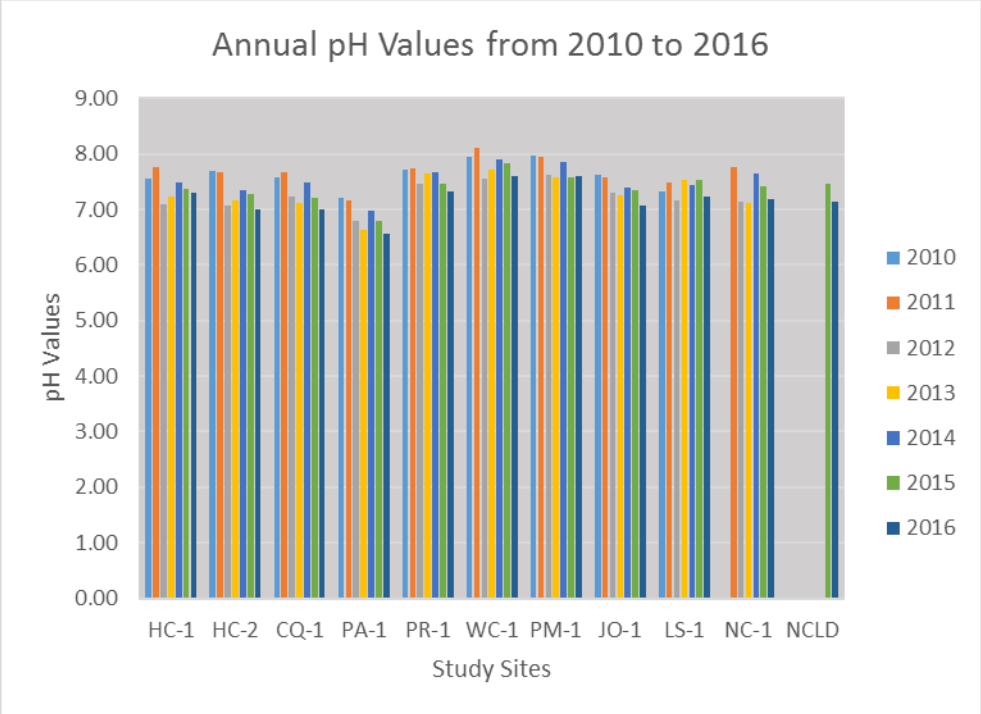

Figure 41. Annual average of stream pH by stream and year.

NTUs (Nephelometric Turbidity Units)

Turbidity levels were typically positively correlated to rain events. Rain events producing runoff increased sediment delivery to streams and are reflected in their turbidity readings. Parr Creek tended to have highest turbidity readings throughout the years due to algae diatom blooms from an upstream wetland pond. Two streams, Horse Creek and Waynita Creek, with active construction or demolition work upstream of the sample locations, at times had elevated levels of turbidity that were unrelated to rain events. The annual average over the study period was below 10 NTUs for background turbidity levels at all sample locations except for Waynita Creek. Its annual average in 2012 was slightly above 10 NTUs at 11.17 NTUs and again in 2015 at 14 NTUs.

Physical

Sediment

A good measure of stream substrate suitability for high diversity of aquatic organisms is percent of fines < 2mm. Percent of fines greater than 15 percent has been found to reduce stream insect diversity and to be harmful to salmonids life histories. In general, city streams had levels of fines greater than 15 percent.

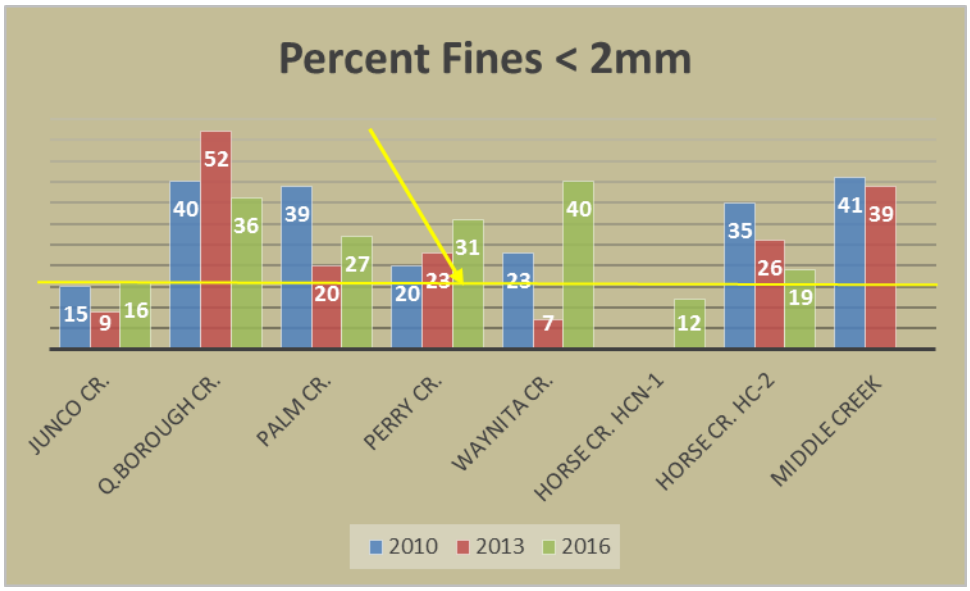

Figure 42. Percent of fines for bioassessment sites by year.

Hydrology Flows

Instantaneous flow estimates were made visually during routine monthly sample events. Most streams tended to exhibit a nonsymmetrical behavior, having peak flows disproportionately higher than the annual average flow observed during low-flow periods. This style of flow data has limited value for assessing streams beyond noting approximate flow volumes on any given sampling day. Figure 43 provides a typical example of annual flow data for relative comparison between streams.

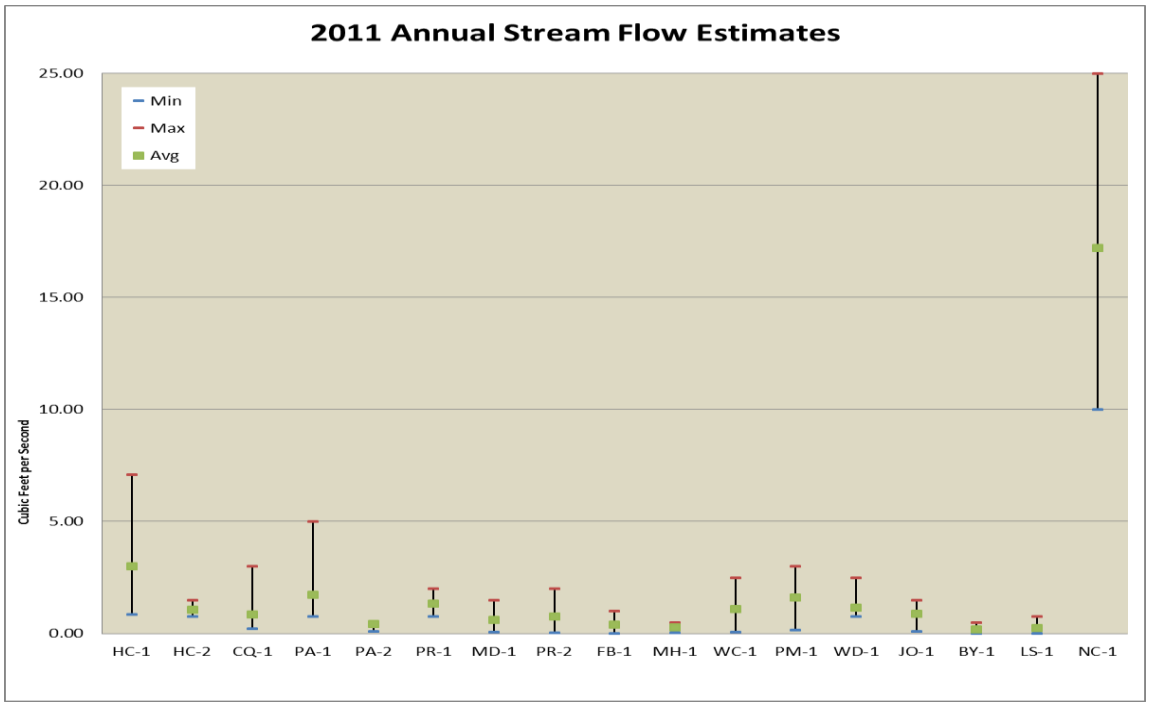

Figure 43. Monthly flow observations for 2011 showing low and high flows by stream site.

Biological

Macroinvertebrate Metrics

Macroinvertebrate samples were collected in August and September 2010 and in mid-August in 2013 and 2016. One replicate sample was collected for quality assurance each year. The replicate's value was within 11 percent in all years. The B-IBI metrics counts for all metrics show similar trends for most streams with two noted exceptions. Four of the sites, Horse Creek, Waynita Creek, Queensborough Creek, and Perry Creek showed a decline or nearly unchanged B-IBI scores since 2010. Junco Creek and Palm Creek had continuous improvement in their respective B-IBI scores (Figure 44).

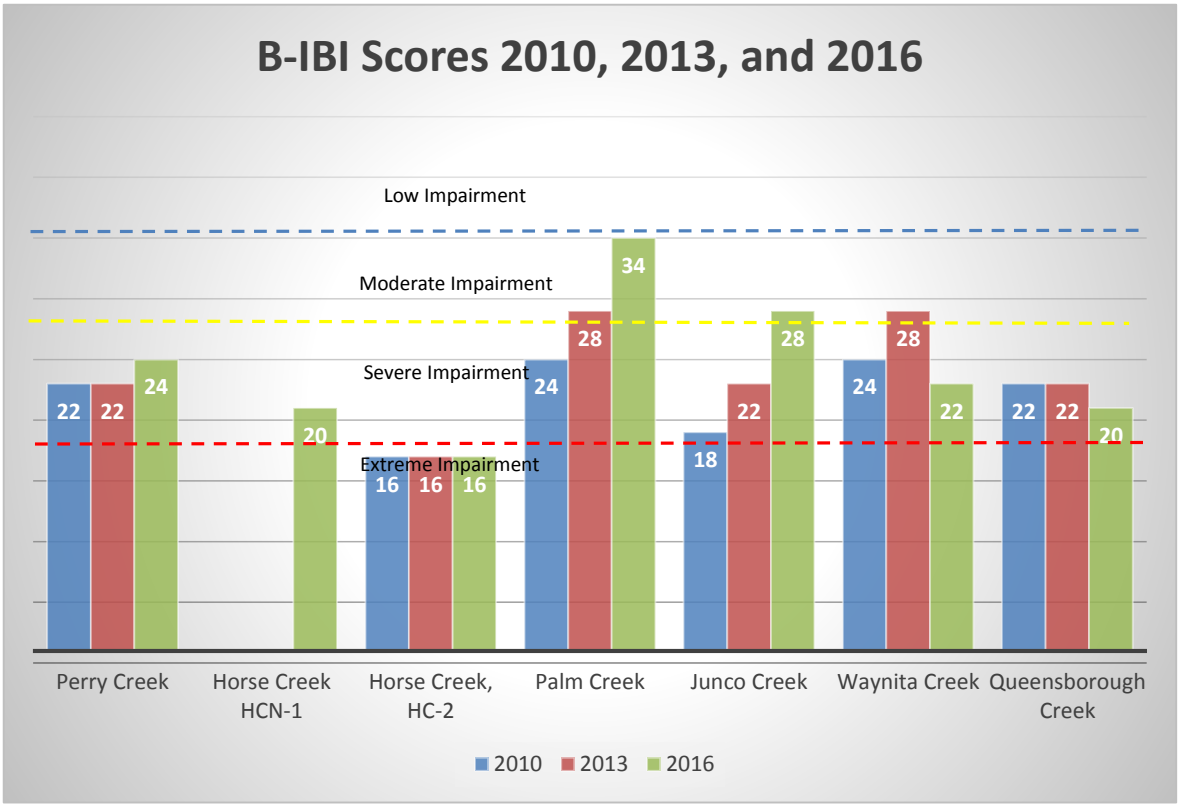

Figure 44. B-IBI scores for 2010, 2013, and 2016.

In general, changes include an increase in percent dominance of the top three most numerous taxa, a drop in total density, vigor, and a loss of long lived taxa and mayflies. Those streams that saw improvements tended to improve for the same reasons. Their predator diversity and long-lived taxa improved and the number of taxa present increased. Predator stream insects are at the top of the food web. Low diversity in predators indicates low diversity of available habitat and prey. Indications suggest that most streams are influenced by low diversity of habitat and prey.

The density of biota in the streams is not a scored metric. However, it does provide a signal that conditions instream are deteriorating such that the density of insects is in decline. The cause of the decline is not well understood. Comparison of flows at the time of the samples was nearly unchanged between years. Hence, this signal could be interpreted as an early indicator that conditions are not improving and might be teetering towards further decline. This low count of taxa within a sample needs further analysis to determine its signal of diversity and health.

Clinger taxa have physical adaptations that allow them to hold onto smooth substrates in fast water (Fore, 1999). They are particularly sensitive to high levels of fine sediment that fill the spaces between gravel and cobble. Most streams had moderate levels of clinger taxa present with the minority of streams having low levels of clinger taxa present. Streams that had less fine sediment typically experienced an increase in clinger richness.

Long-living taxa require more than one year to complete their life cycles. They are exposed to all the human activities that influence the stream throughout one or more years. They are good indicators of low-flow conditions and catastrophic events that can reduce or eliminate all stream insects within a short period of time. Examples of catastrophic events could include a chemical spill or discharge, low dissolved oxygen levels, periodic dewatering, and temperature extremes. Most streams had an increase in long-lived taxa over the study period. This indicates that during the study period no catastrophic events concerning flows or spills occurred.

Blackfly larvae, *Simulium*, tended to dominant most streams and often represented the largest percentage of taxa present. Blackfly larvae abundance typically indicates heavy nutrient enrichment. They are collector filter feeders using sticky hair-like fans. They represent more generalist species, as opposed to those which require special foods or particular types of physical habitat. Most streams had no wood-consuming macroinvertebrates. This correlates with the findings of most streams being devoid of instream wood.

Fish

For general comparison purposes, Table 9 summarizes the fish diversity integrity score for each stream by year. Most fish diversity scores remained unchanged except for Queensborough Creek which saw a decline due a reduction in salmonid age classes. The fish diversity score is based on a 1 through 5 with 5 being the best. A score of 1 means no fish were present.

Table 9. Fish assessment and diversity score results for 2013 – 2016.

	# of Native Species			# of Non-Native Species			# of Salmonid Age Classes			# of R. Sculpin Age Classes			Diversity Score		
Year	2010	2013	2016	2010	2013	2016	2010	2013	2016	2010	2013	2016	2010	2013	2016
Stream															
Junco Cr.	1	2	2	0	0	0	3	3	2	0	1	3	**3**	**3**	3
Q.Borough Cr.	2	2	1	0	0	0	3	1	1	1	0	0	**3**	**2**	2
Palm Cr.	2	2	2	0	0	0	2	3	3	1	2	4	**3**	**3**	3
Perry Cr.	2	2	2	0	0	0	2	3	2	0	0	0	**3**	**3**	3
Waynita Cr.	1	3	2	0	0	0	2	2	2	0	1	2	**3**	**3**	3
Horse Cr. HCN-1			1			1			0			1			2
Horse Cr. HC-2	0	0	0	0	1	0	0	0	0	0	0	0	**1**	**1**	1

Stream Health

Overall stream health was derived from eight aquatic attribute metrics, Table 10. It is a relative means to determine health along measurable and repeatable surveys across time. These attributes represent the chemical, physical and biological components typically associated with stream health.

The overall trend among streams has been one of decline in stream health. Some metrics remained nearly unchanged through the study period, 2010 to 2016, and include; channel substrate, aquatic habitat, fish diversity, and large instream wood. Metrics that have shown a decline include: macroinvertebrates, stream temperature, dissolved oxygen, and pH. Only one metric, stream insects, on one stream, Palm Creek, showed continuous

improvement over the study period. All others were nearly unchanged or had declines in their B-IBI stream insect scores.

Sites did not change their relative cumulative score ranking between years. Horse Creek is the most degraded stream. Palm Creek was the best for in stream health followed by Junco Creek and then Waynita Creek.

Table 10. Summary select attributes for cumulative (C) score for bioassessment sites by year (2010/2013/2016).

Watershed	Channel Substrate	Aquatic Habitat Diversity	Fish Diversity	Macro Invert. Integrity	Large Organic Wood	Stream Temp.*	Dissolved Oxygen	pH	Cum Score
									Cum
Junco Cr.	1/2/1	1/1/1	3/3/3	2/2/3	1/1/1	1/5/3	4/4/3	2/2/2	**15/20/17**
Q. Borough Cr.	1/1/1	1/1/1	3/2/2	2/2/2	1/1/1	1/2/1	3/4/3	2/1/1	**14/14/12**
Palm Cr.	1/1/1	1/1/1	3/3/3	2/3/3	1/1/1	5/5/4	5/3/4	2/2/2	**20/21/19**
Perry Cr.	1/1/1	1/1/1	3/3/3	2/2/2	1/1/1	1/2/2	4/4/3	2/2/2	**15/16/15**
Waynita Cr.	1/2/1	1/2/1	3/3/3	2/3/2	1/1/1	2/2/2	4/4/4	2/2/2	**16/19/16**
Horse Cr. HCN-1	2	1	2	2	3	2	4	1	**16**
Horse Cr. HC-2	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/2/2	4/4/3	2/2/1	**12/13/11**

Table 11 uses the cumulative score index to classify level of impairment from good, to moderate, poor, and severe. Most streams remained unchanged with Queensborough Creek watershed showing decline in 2016 from poor to severe. Palm Creek declined from a moderate to poor in 2016.

Table 11. Stream health status conditions for bioassessment sites.

Watershed	2010	2013	2016
Horse Creek	**Severe**	**Severe**	**Severe**
Waynita Creek	**Poor**	**Poor**	**Poor**
Perry Creek	**Poor**	**Poor**	**Poor**
Junco Creek	**Poor**	**Poor**	**Poor**
Q.Borough Cr.	**Poor**	**Poor**	**Severe**
Middle Creek	**Severe**	**Severe**	**Not sampled**
Palm Creek	**Poor**	**Moderate**	**Poor**

Table 12 prioritized the Surface Water Management Areas based on their individual cumulative score index by year. There is little change in the rankings between years. The SWMAs scoring finds Horse Creek being worst followed by Queensborough and Waynita and Canyon Park tied for third. Fitzgerald SWMA was least impaired. If Middle Creek had been sampled in 2016 and included, the assessment of Canyon Park SWMA would most likely have been second-most impaired, ahead of Waynita and Queensborough SWMAs.

Table 12. Ranking by year by cumulative score index for SWMA(s). The lower the score the lower the overall instream health.

Surface Water Management Areas	2010	2013	2016	Sum of Scores	Worst to Best
Horse Creek	**2**	**2**	**1**	5	1
Waynita	**5**	**5**	**5**	15	**4**
Queensborough	**4**	**4**	**3**	11	**3**
Canyon Park	**5**	**6**	**4**	15	**4**
Queensborough	**3**	**3**	**2**	8	**2**
Canyon Park	**1**	**1**	**Not sampled**		
Fitzgerald	**6**	**7**	**6**	19	**5**

Summary

Results for ambient water quality monitoring and bioassessments found degraded conditions throughout the city. Best available science has frequently found such levels of degradation to be related to common and pervasive urban development. Urban development is often characterized as having: a dense road network, high levels of impervious surfaces, loss of riparian corridor (treed streamsides), an increase in peak storm flows, inadequate storm runoff controls, reduced wetland acreage, modified stream channel networks, and degraded water quality. It may also include an increase in heavy metals concentrations, nutrients, pesticides and herbicides, and a loss of instream and terrestrial habitat, as well as a decrease (and in some cases extirpation) of native species.

Conclusion

The simple answer to the study's question, "Are things improving in our streams?" is "No." While some measures improved between 2010 and 2013, by 2016 they showed a decline. There was improvement in a few streams related to reduction of fines in the stream substrate in 2013. The improvements were temporary. Comparing the results from the eight aquatic metrics used to derive the cumulative score indicate conditions on the edge of further degradation.

The results indicate a need to reconsider current management strategies. The recommendation is to evaluate the current management approaches in light of the City's goal to protect and restore the health of city streams. The evaluation should investigate individual program actions to determine those that produce improvement from those that either insignificantly do or do not produce improvements.

Future

To address the impairments noted in this study, the following are recommended actions:

- ✓ Reduce peak flows, discharge of fine sediment, and polluted storm water to streams.
- ✓ Promote Low Impact Development techniques for new development and re-development; and, where feasible, retrofit existing underperforming storm water systems.
- ✓ Identify means to retrofit systems that direct discharge storm water that has been inadequately treated for pollutants and flow volumes.
- ✓ Encourage landowners to enhance and increase riparian zones along streams and wetlands, while *eliminating* future encroachment.
- ✓ Develop and prioritize a watershed-based restoration schedule to address instream deficiencies.
- ✓ Allow for and protect stream channel migration zones within floodplains.
- ✓ Educate landowners on improved vegetation management techniques that reduce applications of fertilizers, herbicides, and pesticides.
- ✓ Develop City plans to reduce road-generated pollutants from reaching streams.
- ✓ Increase forested canopy throughout the city that promotes forested hydrologic maturity runoff conditions.
- ✓ The City's National Pollution Discharge Elimination System Phase II Permit should be closely structured around the identified sources of degradation identified in this report.

Monitoring is recommended to continue for future trend and effectiveness analysis. However, the monitoring program should evaluate the usefulness of the sites selected and the need to continue the current monthly ambient monitoring except in years of bioassessments. In 2017, only designated TMDL sites will receive monthly ambient monitoring until the program evaluation is completed. Further investigation is recommended to determine the influence that fish populations have on B-IBI scores. Can they suppress or enhance B-IBI scores based on different fish populations feeding strategies?

The results here provide a means to measure the effectiveness over time of the City's critical areas protection and surface water program towards meeting the goal to protect and restore the chemical, physical, and biological integrity of the city's surface waters.

Literature Cited

Bullchild, Lyman, Scott Hall, Allen Pleus, and Dave Schuett-Hames eds. Timber Fish and Wildlife. TFW Ambient Monitoring Program Manual. TFW-AM9-93-001. Northwest Indian Fisheries Commission, Washington Department of Natural Resources. 1993.

City of Bothell, 2016. Bothell 2015 Storm and Surface Water Master Plan Update. City of Bothell, Surface Water Division, Public Works, 18415 101st Ave NE, Bothell, WA 98011.

City of Bothell. Bothell Municipal Code: Title 14, Environment. Bothell, WA: September 2006.

City of Bothell. Imagine Bothell…Comprehensive Plan. Bothell, WA: 1997-2005.

Fore, L.S. Measuring the Biological Integrity of Puget Sound Lowland Streams: Description and Calculation of the Benthic Index of Biological Integrity (B-IBI). Seattle, WA: University of Washington, 1999.

Haley, Duke, J. and William G. Jonsson, 2014. Percentage of impervious surfaces in twenty-two watershed basins City of Bothell. University of Washington Bothell.

Karr, J.R. and E. W.Chu. 1999. *Restoring Life in Running Waters*. Island Press

Loch, Andy. Evaluating Effects of Land Use Management of Physical and Biotic Conditions of Small Streams in Puget Sound Ecoregion. Progress Report No. 07. Tulalip Tribes Natural Resources Division. Marysville, WA: 2000.

… 2011. 2010 Stream Health Assessment for City of Bothell Streams, City of Bothell, Surface Water Division, Public Works, 18415 101st Ave NE, Bothell, WA 98011.

2012. 2011 Stream Health Assessment for City of Bothell Streams, City of Bothell, Surface Water Division, Public Works, 18415 101st Ave NE, Bothell, WA 98011.

2014. Health Assessment of City of Bothell's Streams, 2010 to 2013. City of Bothell, Surface Water Division, Public Works, 18415 101st Ave NE, Bothell, WA 98011.

2015. 2014 Stream Health Assessment for City of Bothell Streams. City of Bothell, Surface Water Division, Public Works, 18415 101st Ave NE, Bothell, WA 98011.

2016. 2015 Stream Health Assessment for City of Bothell Streams. City of Bothell, Surface Water Division, Public Works, 18415 101st Ave NE, Bothell, WA 98011.

May, C.W. "Assessment of cumulative effects of urbanization on small streams in the Puget Sound Lowland ecoregion: implications for salmonid resource management." Ph.D. Diss. University of Washington, Department of Civil Engineering, Seattle, WA: 1996. 383.

Rosgen, David L. "A Classification of Natural Rivers." Catena: An Interdisciplinary Journal of Soil Science, Hydrology, Geomorphology, Focusing on Geoecology and Landscape Evolution 22.3 (1994): 169-99.

Plotnikoff, R. W., and S. I. Ehinger. Using Invertebrates to Assess the Quality of Washington Streams and to Describe Biological Expectations. Publication No. 97-332. Washington State Department of Ecology, Ambient Monitoring Section. Olympia, WA: 1997.

Scholz, Jenna G., and Derek B. Booth. Monitoring Urban Streams: Strategies and Protocols for Humid-Region Lowland Systems. University of Washington, Center for Urban Water Resources Management. Seattle, WA: 1999.

Spence, Brian C., Gregg A. Lomnicky, Robert M. Hughs, and Richard P. Novitzki. An Ecosystem Approach to Salmonid Conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp. Corvallis, OR: 1996 (Available from the National Marine Fisheries Service, Portland, OR.)

Whiteway, Sarah L., Pascale M. Biron, André Zimmermann, Oscar Venter, and James W.A. Grant. "Do in-stream restoration structures enhance salmonid abundance? A meta-analysis." Can. J. Fish. Aquat. Sci. 67 (2010): 831-41.

Zaroban, Donald W., Mulvey, Michael P., Maret, Terry R., and Hughes, Robert M. 1999. Classification of Species Attributes for Pacific Northwest Freshwater Fishes. Northwest Science, Vol 73. No. 2. 1999, pgs 81 to 93